A Review on Low Voltage Ride Through Capability in Wind Turbines of India and Challenges in Implementation

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***Abstract*—The increase in penetration of wind power to grid has made Low Voltage Ride Through (LVRT) an imperative capability, to ensure grid security. Therefore, necessary grid code standards have been established in various countries to ensure operation of wind turbines during the fault conditions without tripping. The objective of this review is to comprehend these challenges in implementation of LVRT capability in India, in order to come up with appropriate solutions. The unforeseen difficulties in the implementation of the LVRT capability pertaining to the policy issues, stability analysis specific to the turbine type required, the additional cost incurred for LVRT augmentation techniques installed, the burden put forth on the manufacturers in terms of investments and the tedious LVRT testing process needed after installation are generally not focused. This paper tries to align the technical requirement and the real-time scenario, this knowledge is quite essential for the industries and academicians working towards renewable energy integration problems and solutions.**

***Keywords*-Doubly-fed induction generator (DFIG), wind turbines, Squirrel cage induction generator (SCIG), Permanent magnet synchronous generator (PMSG), fault ride-through (FRT), low voltage ride through (LVRT).**

I. INTRODUCTION

The large wind power generation has led to demanding grid code requirements [1]. There are two important requirements in wind power: reactive power control during normal operating conditions and Low Voltage Ride Through (LVRT) capability requirements during fault conditions [2]. LVRT is an imperative capability for wind turbines to ensure its grid security [3]. The grid code for LVRT varies with each country based on the requirement of the 'Transmission System Operators' (TSOs) [4]. But the real-time challenges in actual implementation of solutions to achieve these grid codes in the wind turbines are often left unfocused [5]. The recent guidelines for mandatory LVRT capability requirement of wind turbines in India, to restore the endangering grid security have brought in several issues to be focused [6].

Therefore, the objective of this review is to comprehend these challenges in implementation of LVRT capability in India in order to come up with appropriate solutions [7]. The unforeseen difficulties in the implementation of the LVRT capability pertaining to the policy issues, stability analysis specific to the turbine type required, the additional cost incurred for LVRT augmentation techniques installed, the burden put forth on the manufacturers in terms of investments and the tedious LVRT testing process needed after installation are generally not focused [8]. Normally, the wind power plants are under private control of 'Independent Power Plant Operators' (IPPO), who may not be willing to invest more on the technical requirements beyond the scope of profit in terms of commercial benefits [9]. In such case, the investors and industries mostly try to identify ingenious ways to minimize the investment costs [10].

With such constraints, implementing the LVRT capability in wind turbines which are already installed and nearing the end of their life time becomes challenging [11]. Also, implementation of LVRT may not ensure profitability for the manufacturers and the implementation becomes challenging without the aid of subsidies [12]. Understanding the operation and need of LVRT requirement is necessary in establishing a co-operation among the system operators, IPPOs which includes the industries and the investors and the energy traders [13]. This is majorly dependent on the laws imposed on the power sector by the country.

This paper tries to align the technical requirement and the real-time scenario, which is quite essential for the industries and academicians working towards renewable energy integration problems and solutions [14]. Although several benefits are offered by installing retrofitting based solutions for LVRT capability in wind turbines like active crowbar [15], Fault Current Limiter (FCL) [16], Dynamic Voltage Restorer (DVR) [17], Static Compensator (STATCOM) [18], etc they are becoming unsuitable for installation due to economic and policy constraints [19]. This review is focused to understand the challenges and opportunities in determining the possible methods suitable for the Indian scenario [20].

The remaining paper is classified as follows. Section II discusses the LVRT capability requirement in India and the grid code standards established in India, Section III discusses the challenges in implementation of LVRT capability, which is based on the requirements specific to various turbine types, additional costs, trouble for manufacturers and the policy issues, Section IV is a discussion on the real time challenges in implementation of additional requirements and ways to overcome this burden and Section V ends with conclusion and discussion.

II. LVRT GRID CODE REQUIREMENTS

The increasing penetration of wind farms in Indian power system will have a major impact. Therefore, the behavior of the wind farms is expected to be same as a conventional power plant and staying connected during system fault is a step towards that direction. The technological growth in wind turbines and power electronics has been helpful to achieve this requirement. LVRT capability grid codes are established in majority of the countries with a substantial wind energy generation. The top five wind power producing countries China, USA, Germany, India and Spain, their LVRT requirements are shown in Fig.1.

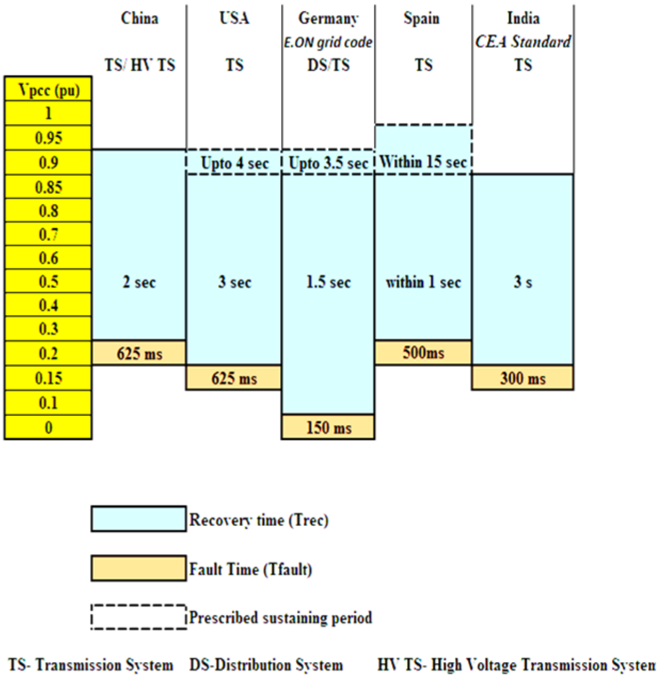

Fig.1. LVRT capability requirement of top five wind power capacity countries.

Indian Wind Grid Code (IWGC) is similar to the international grid code standards and the fault clearing time is based on the Indian Electricity Grid Code (IEGC). Generally, wind farms connected below 66 kV can be disconnected from the grid during system faults, since they are smaller in size and do not affect the grid stability by large. But wind farms connected above 66 kV need to stay connected during system faults and provide reactive power compensation to support the grid for fault recovery.

The LVRT requirement is pertinent to all new wind farms planned or commissioned after 15.4.2014 [21].Sub-clause (3) Clause B (2) of Part-ll of the Central Electricity Authority (Technical Standards for Connectivity to the Grid) (Amendment) Regulations, 2012 provides that LVRT is compulsory for wind turbine generators installed after 15.4.2014.

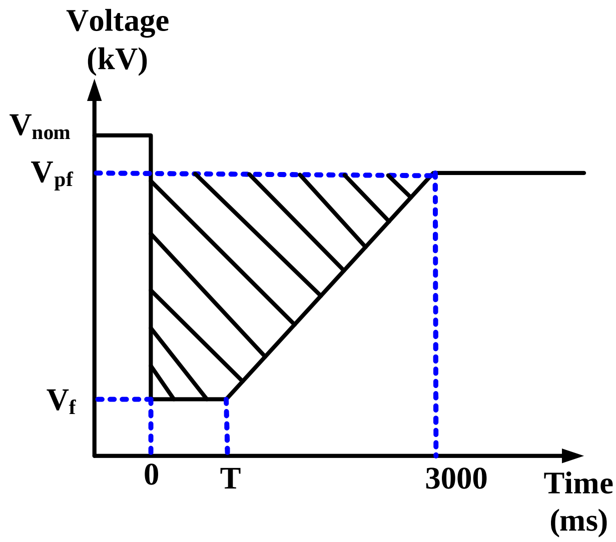

Fig.2 LVRT capability requirement in India

The Fig.2 shows the LVRT capability requirement for wind farms connected at 66 kV and above to be connected within the shaded region and can be disconnected otherwise. V_{pf} is the minimum voltage mentioned by IWGC, which is 80% of the nominal system voltage (V_{nom}) and V_f is 15% of the the nominal system voltage. The fault clearing time 'T' varies based on the different system nominal voltage levels as shown in Table I.

Table I. Different fault clearing time based on system voltage levels

S.No	Nominal system voltage (kV)	Fault clearing time, T (ms)	V_{pf} (kV)	V_f (kV)
1.	400	100	360	60
2.	220	160	200	33
3.	132	160	120	19.8
4.	110	160	96.25	16.5
5.	66	300	60	9.9

In addition, wind farms are required to contribute to the voltage restoration of the power system by injecting the maximum possible current during the fault and the recovery period, while maintaining the operating point within the shaded area. Therefore as per the requirement, wind turbine generators of the wind farms are expected to provide the following: 1. To minimize the reactive power drawl from the grid and 2. The wind turbine generators need to provide active power in proportion to the retained grid voltage as soon as the fault is cleared.

III. CHALLENGES IN LVRT IMPLEMENTATION IN INDIA

The challenges in implementation of LVRT capability in wind turbines of India are discussed in this section.

A. LVRT Requirement Based on Turbine Types

Basically, there are four types of wind generators which are classified as Type 1, Type 2, Type 3 and Type 4. Type 1-Fixed-speed Induction Generator (Squirrel Cage Induction Generator, SCIG), Type 2- Wound Rotor Induction Generator (WRIG) with variable rotor resistance, Type 3-Doubly Fed Induction Generator (DFIG) (WRIG with partial-scale converters), Type 4-Wound Rotor Synchronous Generator (WRSG) (Permanent Magnet Synchronous Generator, PMSG). The Fig.3 shows the various stages of fault: 1. Pre-fault (No fault condition), 2. During fault (requires LVRT support), 3. Post-fault (should restore to normal condition which is pre-fault).

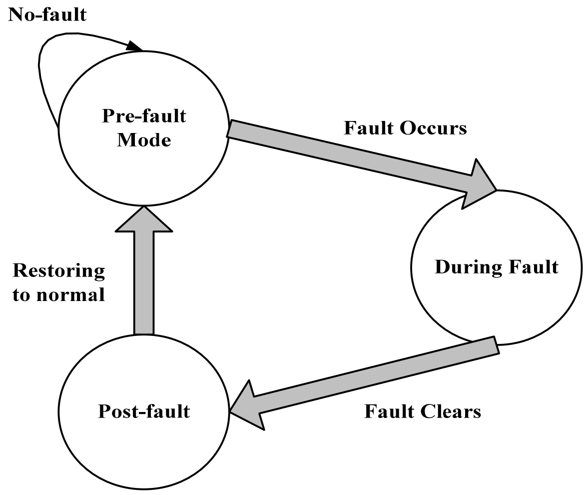

Fig.3. Stages of fault

The LVRT capability operation varies with the type of wind turbine. The type 1 is the early version of wind generators which have a fixed-speed turbine connected to the grid directly through transformer. Since, SCIG is similar to the operation of an induction generator; it draws reactive power and therefore uses a capacitor bank for reactive power compensation. During fault operation, the terminal voltage drops which prompts to critical reduction in electromagnetic torque and electric power yield of the generator. This type of wind turbine requires external grid support based on crowbar and FACTS devices.

Type 2 wind turbines are slightly different from the type 1 generator, with an extra rotor resistance which can be shifted by optically controlled converter mounted on the rotor shaft. LVRT capability through external control for voltage recovery as discussed for type 1 are preferred.

Type 3 is the most popular type of wind turbine and since the wind generator has partially scaled converts it is very sensitive to grid faults. Unbalanced faults may cause stator current oscillations that lead to high inrush rotor currents due to stator and rotor coupling. This will affect the transient performance of the DFIG based generators.

The type 4 PMSG is a variable speed generator with a direct-driven generator which consists of a synchronous generator and a full-scale power electronic converter. PMSG based turbines have a better LVRT capability due to the full-scale power converters employed and mostly prefer software or control based LVRT solutions.

Some of the old wind turbines of up to 700 kW and with stall regulation, the provision of putting add on LVRT is technically not possible. In India, about 11,510 such turbines were installed till April, 2014. The Central Electricity Authority (CEA) may undertake a study on this aspect and give its suggestions in this regard. The LVRT capability available in the state of Tamil Nadu as per the report [21] is shown in fig.4.

For more than 700 kW turbines and with pitch regulation, the provision of LVRT as retrofit is possible. However, it is not possible to purchase such turbine type/model and then it can be mass produced and retrofitted on these turbines. Further, in some turbine models, the retrofitting of LVRT would also require modifications in the turbine structure for additional strength to absorb the mechanical stress of the LVRT, which would cause in the fault situation. For old turbines, which were not originally designed for LVRT, adding the LVRT feature by way of retro-fitting would result in increased loads on the turbine especially in its drive train and related components. The present drive train and related components can only take this additional load, if there was a higher margin considered while designing [22].

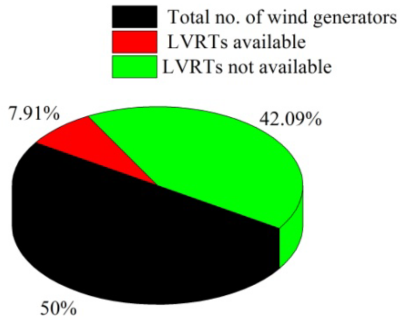

Fig.4. LVRT capability of Tamil Nadu India

B. Additional Costs Incurred

Installation of LVRT device on wind turbines which were installed before 2014 are currently unviable due to the exorbitant cost. While future wind energy generators being established are in position to take into account the installation of LVRT devices and plan their affairs including the tariff terms and conditions, taking into account the financial implication of LVRT installation to require installation of LVRT devices for existing pitch regulated machines without addressing the issues of commercial and viability, cannot be done.

Indian Wind Power Association (IWPA) has requested to relax LVRT requirement for wind farms where the sub-stations are completed prior to coming into force of these regulations and where one or few turbines are being installed ought not to be insisted upon with LVRT protection.

With regard to commercial implications, Indian Wind Turbine Manufacturers Association (IWTMA) has submitted that the retrofitting of LVRT would require additional investment by the wind generators. The cost of LVRT solution for a single turbine is estimated to be in the range of 30000 USD to 80000 USD, irrespective of turbine capacity which would put a lot of financial burden on the manufacturers.

It is imperative that a financing mechanism would definitely require for retrofitting of LVRT on existing turbines for successful implementation. Even after financing of LVRT, the generators needs to be required compensated for the additional capital expenditure. In case of wind power projects, there are following three models for off-take of power: (i) Sale to Discom: Tariffs are levelised tariffs based on capital cost assumed at the beginning of the tariff period and fixed for the tariff period. For recovery of capital expenditure, the tariff would need to be increased by respective State Commissions. Only after such tariff revision, retrofitting of LVRT on old turbines can be successfully implemented. (ii) Sale of power though Open Access: The additional cost incurred due to retrospective implementation of regulation would result in loss to the generator as the purchaser of power may or may not agree to pay the additional cost. A solution for such scenario is essential as such projects may prove to be impediment to the implementation. (iii) Captive consumption of power: Since the additional retrofitting cost would result in effective loss and needs to be addressed as under: a. Providing LVRT on wind turbines would help in grid management, however it alone cannot guarantee it. There are other measures, which should be implemented simultaneously. b. In case of implementation of LVRT on turbines connected prior to 15.4.2014, the same needs to undertaken with mutual agreement.

The implementation plan for such turbines must be devised based on the (i) technical constraints, (ii) implementation limitations due to high number of turbines, and (iii) compensation to generators for retrofitting of LVRT on old turbines In view of the above, a time frame of 3 years would be required with adequate funding arrangement along with cost recovery to implement LVRT on wind turbines.

C. Burden on Manufacturers due to Investments and Processof Implementation

The implementation of LVRT on turbines connected before April, 2014 would pose a challenge of scales as there are about 25807 wind turbines connected prior to April, 2014. Out of these, there would be about 14,346 turbines of more than 750 kW on which LVRT needs to be implemented. These turbines have been manufactured by about 48 different manufacturers. Out of these, there are about 28 manufacturers who have manufactured the turbines of capacity of more than 750 kW. Out of these 28 manufacturers, only 14 are still in the business of manufacturing of wind turbine.

There are about 2000 owners of such turbines who will have to invest and provide LVRT. As per the information available, at present, there are no suppliers of LVRT, which is understandable as the LVRT needs to be designed, in case of retrofitting, for each model/type of turbine. In case of new turbines, which are LVRT compliant, the LVRT feature is part of turbine design. Therefore, it is not procured from suppliers and added to the turbines.

This limitation of designing and suppliers of LVRT required to be considered while considering time frame to implement LVRT on existing turbines.

D. Policy Issues

Turbines manufactured as per the existing regulations does not have LVRT,therefore, the certificate also does not include the LVRT. For turbines in which the design margins permit for adding the LVRT by way of retrofit, the Type Certification of turbines would no longer remain valid which could potentially affect the insurance of the turbine in case of major damage occurring to the turbine for any reason.

In case of retrofitting of LVRT, if utilities insist on the wind turbine type certification of the entire type certification process which is time consuming and involves substantial cost approximately Rs. 3.00 crore per certification.

Therefore, provision of LVRT should be certified from the competent authority and inclusion of the same in turbine test certification should not be insisted upon and sufficient time would need to be provided for implementation of LVRT on old turbines.

IV. Conclusion and Discussion on LVRT Implementation in India

IWTMA has submitted that till April, 2014, there are about 11,510 Stall Type turbines installed in India up to 700 kW and with Stall Type, adding LVRT even as a retrofit is technically not possible. In this regard, CEA should undertake a study and come out with suggestions.

IWTMA has submitted that for the other turbines with capacity more than 700 kW and with pitch regulation, the provision of LVRT as retrofit is possible. Further, in some turbine models, the retrofitting of LVRT would also require modifications in the turbine structure for additional strength to absorb the mechanical stress of LVRT, which would cause in the fault situation.

For old turbines, which were not originally designed for LVRT, adding the LVRT feature by way of retro-fitting would result in increased loads on the turbine especially in its drive train and related components. The present drive train and related components can only take this additional load, if there was a higher margin considered while designing.

i. As per IWTMA, around 11% of WTGs are "Stall" type in which retrofitting with LVRT is not commercially viable. "Stall" type WTGs are still being commissioned which amount to 2-3% of total annual additional of WTGs in which too, putting LVRT is not technically/commercially viable.

ii. In the remaining commissioned WTGs (around 89%), there are some models where manufactures may not support retrofitting.

iii. Barring above WTGs, all other WTGs can be retrofitted with LVRT. For more than 97% of annual additional WTGs, LVRT can be provided.

iv. Provision of STATCOMS at pooling sub-station level in place of LVRT at WTGs does not seem to be a commercially viable solution especially since this may increase the cost.

v. IWPA requested to explore a suitable mechanism to meet the incurred expenditure instead of either loading the expenditure on wind farm owners or reworking PPA since many agreements are third Party sales arrangement or wheeling and banking arrangements.

Also, IWTMA has contended that non-availability of LVRT is not the reason for loss of wind generation during grid disturbances/grid incidents and cascade tripping of wind mills. The main reason for loss of wind generation during grid disturbances/ grid incidents and cascade tripping of wind mills is due to non-availability of wind evacuation system with 400 kV sub-stations and transit lines.

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