Survey on LVRT Capability Enhancement of Single-Phase Grid Connected PV Array with Coupled Supercapacitor

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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. Low-voltage ride through capability is among the challenges in the operation of medium and large scale grid connected photovoltaic power plants. In addition, reactive power injection during voltage sags is required by power system operators in order to enhance the voltage of the point of common coupling.*

Keywords: *LVRT, Photovoltaic, Grid connected, Supercapacitor, Single Phase,*

I. Introduction

As the PV penetration to the grid is getting higher, dynamic stability is becoming a matter of utmost importance. Grid-codes are strictly maintained for the PV integration to the grid and the most widely employed one is the E.ON code, imposed by Germany. Among the grid-codes, low-voltage ride-through (LVRT) capability is particularly important along with dynamic voltage support by supplying required reactive current after the grid-fault initiation. Fig.1 shows the grid-codes which are imposed by different countries and grid-connected PV system must sustain the voltage profiles as indicated in the fig.1. Also, German grid code requires supplying reactive current to the grid during voltage sag as shown in fig.1 [3]. A nominal level of reactive current must be inserted to the grid for dynamic voltage support during the voltage dip in the Grid Code of Great Britain and Denmark. The issue of addressing the LVRT technique for renewable energy sources is adopted in different ways. For the large PV plants, an LVRT method is proposed; however, the proper active power insertion and the DC link protection during the grid disturbance are not discussed. The methodology proposed is only capable of managing the symmetrical fault by inserting both active and reactive powers at low to medium voltage networks and also does not consider the DC link protection [3]. A protection scheme is adopted depending on the symmetrical components to cope with the LVRT issue, but, it has the shortcoming of the high current stress on unbalanced and low gird voltage. Although the positive and negative sequence components were considered in to insert active and reactive powers at LVRT period without exceeding the inverter current limit, however, the DC-ink

protection scheme was not considered. The most widely employed LVRT method is the application of a resistor with chopper circuit across the DC link. The presence of the grid fault causes the series resistor in operation, which dissipates the PV generated power to balance the power between both sides of the inverter. Although the DC link overvoltage is protected by this method, this method is not capable of supporting the voltage during the grid fault. Also, a methodology of inserting reactive current within the inverter current limit employing transformer flux compensation was proposed. However, the proper balance in active power generated by the PV generator and the power inserted to the grid during the grid disturbance has not been addressed so far. The penetration of PV to the grid renders to a nonlinear system, where these nonlinearities are incurred by intermittent behaviour of solar intensity, and the switching phenomena of the inverters and power converters.

Hence, the widely employed nonlinear controllers such as fuzzy controller, adaptive-network-based fuzzy inference system (ANFIS) or static nonlinear controller can be designed for dealing with the nonlinear systems. The fuzzy logic is a powerful tool that has prevalent applications in embedded control systems and information processing. It is capable of providing definite conclusions in a very simple way from vague or ambiguous information. It works well for any nonlinear and uncertain situations [3].

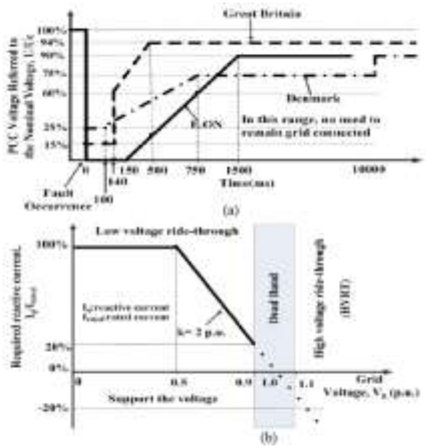

Fig.1Grid code: (a) voltage requirement, (b) reactive current requirement.

II. Literature Survey

P.Mohammadi et al.[1] "LVRT Capability Enhancement of Single-Phase Grid Connected PV Array With Coupled Supercapacitor", This paper has demonstrated the ability of supercapacitor to improve the performance of single phase grid connected PV system during grid faults. Performance of reactive power injection strategies in the terms of the effect on DC side voltage and power fluctuations was explored. It was observed that constant current peak control strategy has the most severe impact on PV MPPT performance and therefore DC side dynamic. Therefore, supercapacitor has a great importance when this reactive power injection strategy is imposed. During a grid fault, the power generated from the PV array will be absorbed by the supercapacitor which leads to minimization of active and reactive power fluctuations. Simulation results confirmed the validity of proposed structure and control strategy.

Hossein Dehghani Tafti et al.[2] "Low-voltage ride-thorough capability of photovoltaic grid-connected neutral-pointclamped inverters with active/reactive power injection", This paper studies the performance of the grid-connected 3L-NPC inverter of medium-scale multi-string grid-connected PVPPs during voltage sags. An algorithm for calculating the dq-axis current references is presented. Based on the grid requirements, the 3L-NPC inverter injects the required active/reactive power to the grid during voltage sags. The proposed control strategy employs the full current capacity of the grid-connected inverter resulting in a better grid voltage enhancement. Detailed implementation of the proposed control scheme has been presented, and its effectiveness are demonstrated through simulation results on a 150−kVA PVPP connected to the 12.47−kV MV test-case system under various voltage sag conditions. Experimental results on a laboratory 3.3-kVA 3L-NPC setup have been presented showing the effectiveness of the proposed control strategy in injecting active/reactive power to the grid during voltage sags.

Md Kamal Hossain et al.[3] "Fuzzy Logic Controlled Power Balancing for Low Voltage Ride-Through Capability Enhancement of Large-Scale Grid-Connected PV Plants", This paper proposes a LVRT capability enhancement technique of a large scale grid connected PV system. Both active and reactive power insertion is maintained according to the E.ON grid code. A fuzzy logic control based active power insertion scheme is incorporated with the conventional MPPT technique for inserting the active power in a controlled manner in the case of grid fault situation. The performance of the proposed scheme is better than that of the conventional two stages inverter/converter control scheme. Based on simulations, the following points are noteworthy.

a) Transient rise of the fault current is limited by the proposed strategy.

b) The proposed LVRT scheme is capable of protecting the DC link overvoltage protection.

c) Reactive current insertion during the low voltage period is utmost important for dynamic voltage support and the methodology proposed in this work is capable of providing reactive current during the low voltage period.

d) Undervoltage tripping of a big PV plant can be prevented by the proposed scheme, since the inverter is capable of providing constant current.

Hany M. Hasanien et al.[4] "An Adaptive Control Strategy for Low Voltage Ride Through Capability Enhancement of Grid-Connected Photovoltaic Power Plants", This paper has introduced a novel application of the CMPN algorithm-based adaptive PI control strategy for enhancing the LVRT capability of grid-connected PV power plants. The proposed control strategy was applied to the DC-DC boost converter for a maximum power point tracking operation and also to the grid-side inverter for controlling the Vpcc and Vdc . The CMPN adaptive filtering algorithm was used to update the proportional and integral gains of the PI controller online without the need to fine tune or optimize. For realistic responses, the PV power plant was connected to the IEEE 39-bus New England test system. The simulation results have proven that the system responses using the CMPN algorithm-based adaptive control strategy are faster, better damped, and superior to that obtained using Taguchi approach-based an optimal PI control scheme.

Yongheng Yang et al.[5] "Low Voltage Ride-Through of Single-Phase Transformerless Photovoltaic Inverters", The LVRT capability of three mainstream single-phase transformerless PV inverters has been explored in this paper. A benchmarking of those inverters has also been presented in terms of efficiency, LVRT capability with reactive power injection, current stresses and leakage current rejection. With respect to the reactive power injection control, three possibilities have been proposed and discussed. The constant peak current control strategy has been verified by experiments. The results show that the HERIC inverter can achieve a high efficiency, but it is not special suitable for use in the next generation PV systems with LVRT capability or reactive power injection. For this inverter, a possible way to ride-through voltage fault is to modify the modulation scheme during LVRT but at the cost of reducing efficiency. The performance of the FB-DCBP inverter is satisfactory in LVRT operation. It can achieve a slightly higher efficiency compared to the FB-Bipolar topology. However, in LVRT operation, a varying common mode voltage appears in the FB-DCBP inverter, which may introduce safety problems. Moreover, due to the high switching frequency for the extra devices of the FB-DCBP, high current stresses might appear and further introduce failures to the whole system.

III. LVRT Grid Code Requirement

The increasing penetration of wind farms in Indian power system will have a major impact. Therefore, the behaviour 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 the 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. 2.

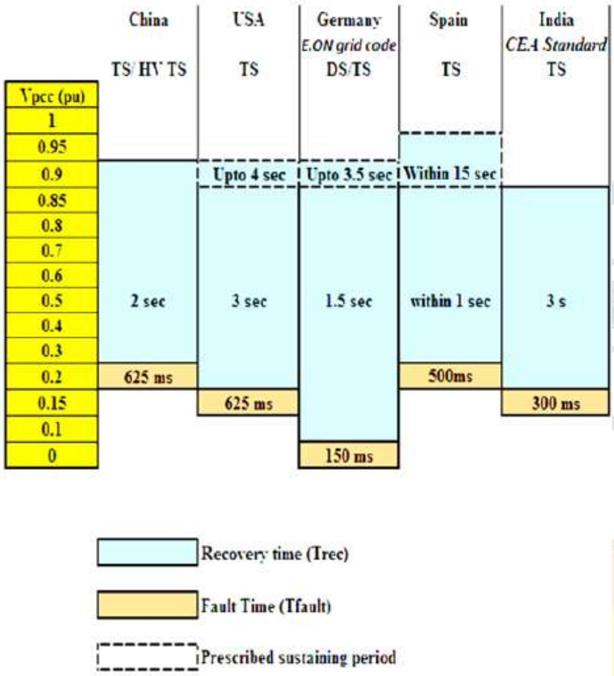

Fig.2 LVRT capability requirement of top five wind power capacity countries

TS= transmission System

DS= Distribution System

HVTS= High Voltage Transmission system

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 66kV can be disconnected from the grid 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. Sub-clause (3) Clause B (2) of part-II of the central electricity Authority Regulations, 2012 provides that LVRT is compulsory for wind turbines generators installed after 15.4.2014.

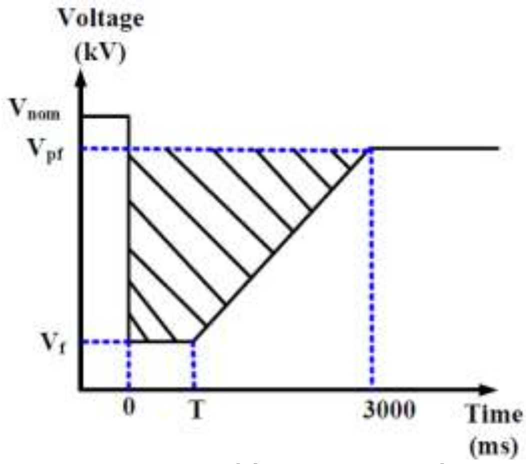

Fig.3 LVRT Capability requirement in India

The fig.3 shows the LVRT capability requirement for wind farms connected at 66kV 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. The fault clearing time 'T' varies based on the different system nominal voltage levels as shown in table 1.

Table 1 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 draw 1 from the grid
2. The wind turbine generators need to provide active power in proportion to the retained grid voltage as soon as the fault is cleared.

IV. Conclusion

This paper has demonstrated study of LVRT Capability Enhancement of Single-Phase Grid Connected PV Array with Coupled Supercapacitor. There are many research papers are surveyed related to LVRT capability enhancement in this paper. The LVRT requirement for grid-connected ESSs is similar to that for other systems such as WPG and SEG systems. In other words, the reactive current needs to be injected into the three-phase grid based on the LVRT requirement.

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