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Z-Source Inverter for PV System with LVRT Capability

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Abstract: *This paper presents a Photovoltaic (PV) application with Power Electronics Interface (PEI). As the penetration of distributed generation systems is booming, the PEI for renewable energy sources should be capable of providing ancillary services such as reactive power compensation and low-voltage ride through (LVRT). This dissertation proposes a robust model predictive-based control strategy for grid-tied Z-source inverters (ZSIs) for PV applications with LVRT capability. The proposed system has two operation modes: normal grid condition and grid fault condition modes. In normal grid condition mode, the maximum available power from the PV panels is injected into the grid. In this mode, the system can provide reactive power compensation as a power conditioning unit for ancillary services from DG systems to main AC grid. In case of Grid faults, the proposed model changes the behavior of reactive power injection into the grid for LVRT operation according to the Grid requirements. Thus, the proposed controller for Z-Source Inverter is taking into accounts both the power quality issues and reactive power injection under abnormal grid conditions. In this system operation is verified experimentally, the results demonstrate fast dynamic response, small tracking error in steady-state, and simple control scheme..*

Keywords: Photovoltaic System, LVRT logic, LVRT, MPPT. ZSI.

I. INTRODUCTION

Power systems are commonly made up of large central power plants that feed power to the transmission and distribution systems to supply the loads. However, due to the recent increasing interest in exploiting renewable energy resources, the distributed generation (DG) facilities that are interfaced directly to the distribution network (DN) are becoming ubiquitous. Photovoltaic (PV) generation systems are one of the most widely adopted DG facilities that are frequently connected to DN. The existing DN was not initially built with a concern for high-level DG integration, thus the recent trend is leading to degraded DN system performance safety, and reliability. Some of the well-known concerns pertaining to the integration of more DG into the DN are the power quality issues, frequency stability, islanding operation mode, voltage stability, protection issues, and increased fault currents. Therefore, several grid codes and standards have been issued to regulate DG systems integration with the DN. The future PV connected to DN should be able to provide a wide range of ancillary services due to grid mandates and codes. Thus, the PV inverters should be able to operate in different modes of operations under grid faults such as intentional islanding and low-voltage ride through (LVRT) mode with reactive power compensation capability. In addition to these ancillary services, highly reliable and efficient power electronics interface (PEI) for PV systems are required to harvest maximum available power from PV panels.

PV systems commonly use two stage power conversion an upstream dc/dc power conversion stage from the PV module to a dc-link energy buffer (such as a capacitor), and a downstream dc/ac power conversion stage from the energy buffer to the grid. The use of a two-stage PEI is required due to the inherent limitation of the conventional dc/ac inverters for regulating the voltage freely. This two-stage power conversion decreases the efficiency of the system and limits the dynamic response of the system in harsh PV ambient condition and grid perturbation. Therefore, an efficient and reliable PEI for PV sources in DG systems requires a single stage power conversion with robust control strategy considering the grid status to meet the grid codes and standards.

A few research works have been recently published focusing on the LVRT operation for two- Stage and single-stage gridtied PV systems using classical multi-loop controllers As mentioned earlier, the two-stage power conversion suffers from low efficiency and limited Dynamic response. The single stage power conversion also suffers from an inability to

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Freely step down/up the voltage, because they are either voltage-source or current-sour Inverters. In addition, LVRT operation appears to be challenging since many additional cascaded loops are required for traditional control scheme of PV systems. In addition, the use of Multi-loop controller causes slow dynamic response under harsh PV Ambient Condition or/and Abnormal grid condition.

Impedance-source inverters are able to overcome several limitations of voltage-source and Current-source inverters. In particular, the Z-source inverter (ZSI) can step up/down The voltage freely [20]; therefore, they are a well-suited single stage PEI for PV sources in DG Systems. However, the ZSIs operation and modulation are different than conventional Inverters due to the existence of impedance network at their input port. Also, the required LVRT Operation will add additional control complexity in comparison with conventional Control Strategies for ZSIs. In, a unified control scheme for grid-tied ZSI for PV an Application is Proposed with reactive power compensation. The presented method uses a Modified space vector Pulse-width modulation (SVPWM) to achieve a shoot-through mode. This requires complex. Modulation scheme with multi–nested-loop control strategy.

II. PROPOSED SYSTEM

he proposed system, illustrated in Fig. 1 with parameters given in Table 1, is tested by MATLAB Software Simulink for several case studies in MPPT mode with normal grid condition and LVRT mode in case of grid voltage sag occurrence. The sampling time Ts is 60 μs; this sampling time is chosen based on the desired performance and complexity of the control scheme A programmable bidirectional ac power source by Chroma (Regenerative Grid Simulator model 61830) is used as the grid in the experiments to emulate lowvoltage scenarios. The switching devices used for ZSI for Inverter Bridge and the diode. The current and voltage sensors are respectively; other system parameters are listed in Table 1.

Table No .1 System Parameters

Sr. No.	Parameter	Value
1	C1	1000 Mf
2	C2	1000 uF
3	L1	0.7 mh
4	L2	0.7 mh
5	Sampling Time	60 uS
6	Cpb	470 uF
7	Lgrid	1 mH
8	Cgrid	470 uF

Fig. 1 illustrates the proposed predictive model of the control objectives for MPC cost function. Figs. 1.a and b show the predictive model of inductor current and capacitor voltage in the impedance network (L1 and C1) for shoot-through mode and nonshoot- through mode, respectively. These predicted models depend on the system model parameters and sampling time TS. Fig. .1 c shows the predicted active and reactive powers (P and Q) for regulating them based on MPPT and LVRT reference generations through MPC cost function (18).The performance of the proposed system is evaluated by looking into the following important merit criteria: harvesting the maximum power with small oscillation around MPP, fast dynamic response under dynamic PV ambient condition, robust operation under grid voltage sag, reactive power injection support in LVRT mode according to grid standards and codes such as E.ON standard , decoupled active and reactive power controls in the MPPT mode without affecting the boosting operation of ZSI, and high quality current injection to the grid considering the THD limits according to IEEE-519 standards. The system is initially tested in normal grid condition with the objective to operate at MPPT with unity power factor. The resulting waveforms for this condition are shown in the scope, remaining in the healthy grid condition, the system is tested through a more realistic scenario in which the grid voltage has distortions. In this model, the highest allowed values of 3rd, 5th, 7th, and 11th-order harmonics according to IEEE-519 standards are added to grid voltage (vg) using a programmable ac power source. As shown in the scope shot of Fig., the control objectives are achieved perfectly even in the presence of grid voltage harmonics.

The performance of the controller during a grid voltage sag event (due to a fault) is tested next. The resulting waveforms are shown in the scope shots of Figs. In this Simulation, the system is initially operating with normal grid condition at

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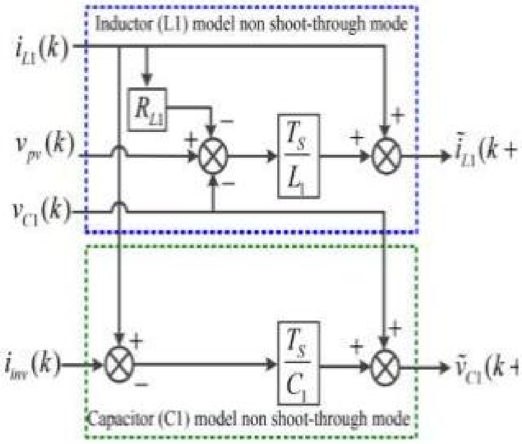
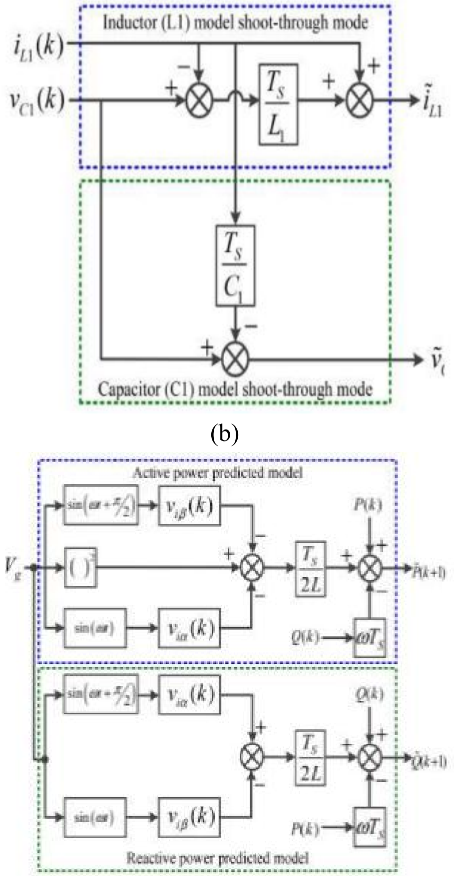
unity power factor. Subsequently, at time instant t1, the sag detector detects 25% voltage sag in the grid voltage and according to the LVRT operation requirement and depth of sag, the ZSI is triggered to inject 400 VAR reactive powers into the grid. As pictured in Fig. 7c, the peak of the grid current is kept constant before and after the reactive current injection, thus achieving the proposed predictive controller objective to maintain constant peak current in this mode of operation. Later, at instant t2 the grid voltage returns to normal condition, and the controller is triggered to return to MPPT operation mode at unity power factor as shown in Fig. This proposed system verifies the MPC-enabled LVRT capability of ZSI and seamless transition between MPPT and LVRT modes for the proposed dual-mode grid-tied ZSI.

The last experiment is examining the response of the system to a change in solar irradiance in normal and faulty grid conditions. The effect of solar irradiance changes in normal grid condition (MPPT mode) is illustrated in Fig. 8a. The solar irradiance is initially at 1000 W/m2, and then at time t3 the solar irradiance is stepped down to 700 W/m2. As pictured, the peak grid current and inductor L1 current are decreased according to the P–V characteristic of the PV panel. The grid current is maintained constant according to the available power from the PV panel and the step change in solar irradiance did not cause any inrush grid current. Fig. illustrates the response of the Proposed system to step change in solar irradiance after the sag detector detects a 25% grid voltage sag and puts the system in the LVRT mode. The solar irradiance is initially at 700 W/m2, then at time t4 the solar irradiance is stepped up to 1000 W/m2. As pictured, this change causes an increase in the grid peak current and inductor L1 current. This case study demonstrates the capability of adjusting the power drawn from the PV panel by moving along the P–V characteristic curve of PV panel according to available solar irradiance and depths of voltage sag to maintain LVRT operation requirement. Finally, the active and reactive powers for experiments in Figs. and are obtained from an oscilloscope and plotted in MATLAB for better observation of dynamic response of the controller when the sag detector detects 25% grid voltage sag. As it is shown in Fig., the level of active power injected into the grid is decreased to provide sufficient room for reactive power injection according to LVRT control mode requirement. Owing to the capability of MPC for predicting the error before applying the switching state to the ZSI, the change in the mode of operation from MPPT to LVRT and vice versa is achieved seamlessly. As it is shown in Fig., the proposed predictive controller for ZSI, without the requirement of challenging tuning in each mode of operation, as a promising dynamic response and high control efficacy in steady-state operation. Similarly, as pictured in the scope, the proposed predictive controller effectively shifts the operating point of the ZSI along the P–V characteristic curve of the PV panel to maximize the energy harvest and provide the required reactive power without inrush grid current or diminishing the grid power quality. The individual harmonic components of the grid side current, ig, are presented in Table .2. The calculated THD of ig is 2.87% which is within the IEEE-519 standards for grid-tied systems. One of the main drawbacks of the MPC is the effect of model parameters mismatch (error) on the controller performance. As an additional performance analysis of the proposed control strategy, Fig. shows the effects of the variations of L1 and L from their nominal values (model parameter mismatch) on MPP tracking accuracy and grid-side current THD.



(a)



(b)

(c)

Fig No.1 Proposed MPC block diagram (a) Predictive model of the inductor current and capacitor voltage (L1, C1) in non-shoot-through mode, (b) Predictive model of the inductor current and capacitor voltage in shoot through mode, (c) Active and reactive power predictive models.

In this figure, the robustness of the proposed control scheme is analyzed from −40 to +80% errors in the L1 and L models, where 0% error demonstrates no model parameter mismatch. Fig. 10a shows the effect of the grid side filter inductance model mismatch on injected current THD. As it is shown for most of the scenarios, the variations of THD values are not much and they are within the IEEE-519 standards and around 2.8% at standard test condition (0% model parameter mismatch). Furthermore, Fig. 1 shows that the variation of the expected MPP from the measured harvested PV power is <5 W which is negligible.

Table No .2 Grid Current Harmonics distortion

Sr. No.	Harmonic Order	Distortions %
1	3rd	0.79
2	5th	1.1
3	7th	0.34
4	9th	0.28
5	11th	0.18
6	13th	0.06
7	15th	0.04
8	17th	0.08

III. SIMULATION MODEL OF PROPOSED SYSTEM

The Matlab Simulink model presents when the 25% grid voltage sag occurs at 0.1s and the system changes its mode of operation from MPPT to LVRT with reactive current injection, & when the grid goes back to normal condition at 0.2s and the system changes its mode from LVRT to MPPT with unity power factor.

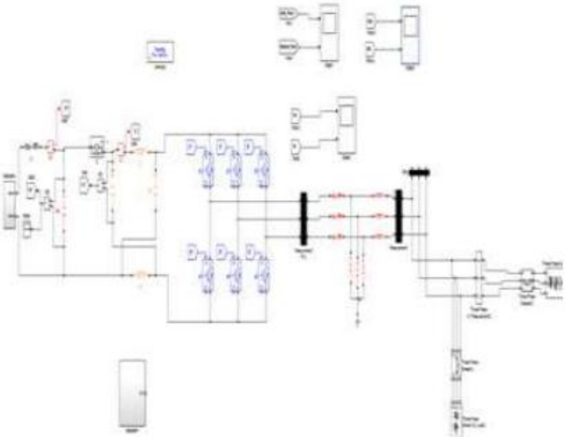


Fig No.2 Simulink model of ZSI for PV System with LVRT

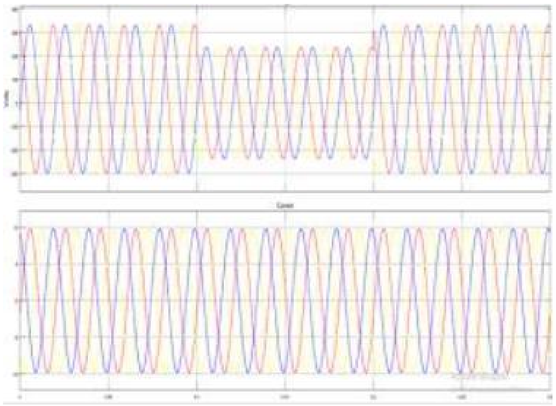


Fig No.3 System performance evaluation to changes in solar irradiance in MPPT and LVRT modes

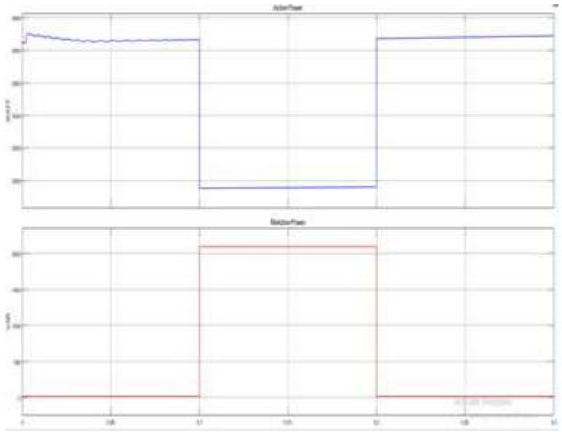


Fig. 4.4 Active and reactive powers when the grid voltage sag of 25% occurs for time intervals t1–t2. The system is Operating in normal grid condition before t1 and after t2

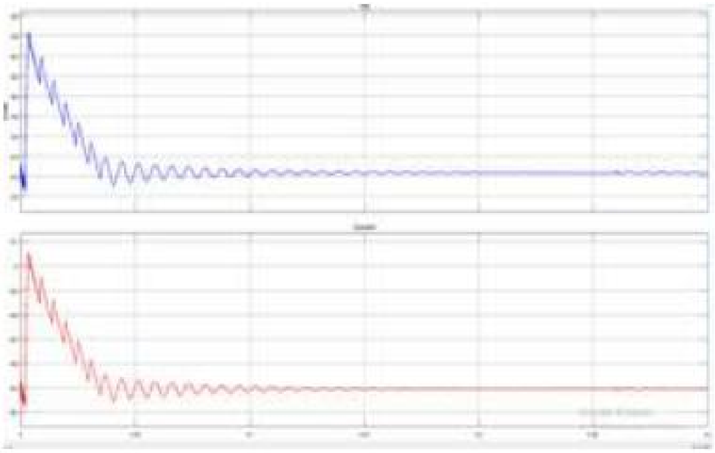


Fig No 4. change in solar irradiance level from 1000 to 700 W/m2 at time 0.1S when the system is operating in MPPT mode under normal grid condition, step change in solar irradiance level from 700 to 1000 W/m2 at time 0.2 when the system is operating in LVRT unity power factor

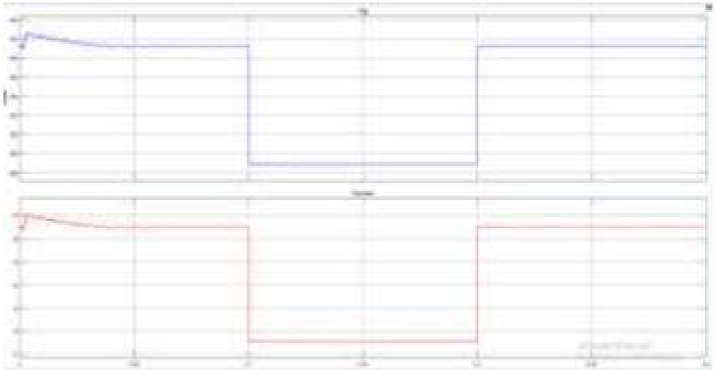


Fig .No 5 RMS value Voltage & current of solar irradiance

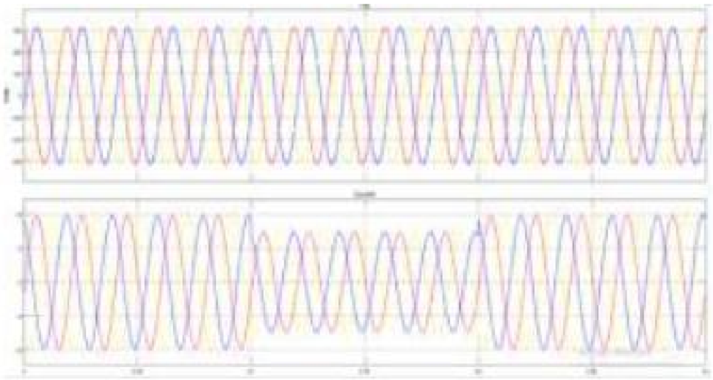


Fig.No.6. Value Voltage & current of solar irradiance

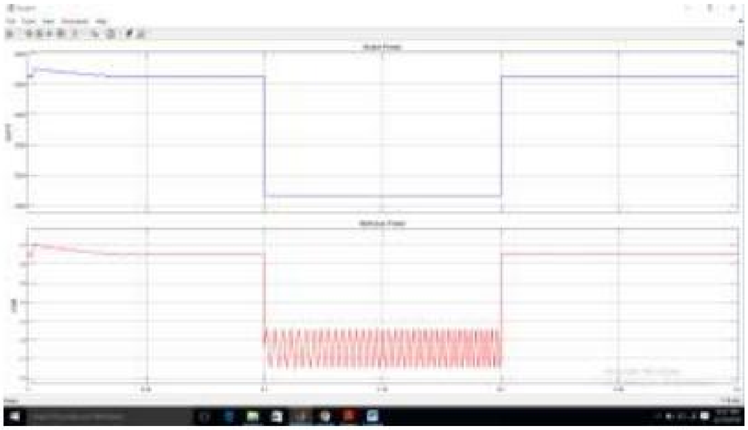


Fig. No 7 Active & reactive power at solar irradiance

IV. CONCLUSION

The dissertation has presented a single-stage PEI based on impedance-source inverter for PV applications with LVRT capability during the grid voltage sag according to grid standards. By using the MPC framework, a simple control strategy is proposed with an adaptive cost function to seamlessly operate under normal and faulty grid conditions. The proposed system eliminates the requirements of multi–nested-loop of classical controller. Owing to the predictive nature of the controller, the proposed system has fast dynamic response to change in solar irradiance or grid reactive power requirement according to LVRT operation. The system is switching between LVRT and MPPT modes of operations seamlessly. The proposed system can be extended for overnight operation of PV sources in DGs with reactive power compensation capability as ancillary service from DG to main grid. Several experiments have been conducted to verify the performance of the proposed system. The results demonstrate robust operation, MPP operation during the healthy grid condition, high-power quality injection during steady-state condition, negligible overshoot/undershoot in grid current injection due to change in solar irradiance or reactive power reference, no observation of inrush current during dynamic change in MPC cost function references for LVRT operation, and maintaining constant peak grid current during the LVRT mode.

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