A New Fast Detection Module for Short-Circuit Current Detection in PV Grid System

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Abstract— In electric power systems, integration of more Distributed Generators (DGs) in the network increase the short circuit level due to the short circuit current contribution of the DGs during faults. As compared to the synchronous and induction machine based generators, the inverter based generators, such as Photovoltaic (PV) solar systems, contributes lower fault current to the network due to the characteristics of PV panels and inverter operation. Although, each PV solar farm may contribute short currents as above, the total amount of fault current contribution may become unacceptably large for a feeder which has several PV systems connected. It is apprehended that short circuit current contributions from multiple solar systems in the distribution feeders may add up to levels that could be damaging to the circuit breakers. As a first step, adequate modeling of PV solar plants for predicting their short circuit contributions during network faults is essential. So far, the above fast faults detection techniques have been used for protection of network and DGs; and for unsymmetrical fault detection in fault current limiters (FCL). However these techniques have not been used to prevent any short circuit current contribution in excess of the rated or utility-acceptable current output of PV solar inverters. In this paper, a new fast detection module for short-circuit current detection has been discussed based on the rate of rise of current together with the current magnitude in a PV solar system based DG. There can be two control operations, as per the applicable grid code in that region, one of which is the disconnection of the PV inverter before the current exceeds the rated output current of the inverter. The second one discusses about transforming the PV inverter into a dynamic reactive power compensator STATCOM and provides grid support functions. A new concept of utilizing PV solar farms as STATCOM (PV-STATCOM) both during nighttime and daytime for different grid support functions was introduced in this paper.

Key words: Photovoltaic (PV) Systems, Distributed Generator (DG), Inverter, Short Circuit Current, Protection, STATCOM, PV-STATCOM

I. Introduction

The interconnection of more Distributed Generators (DGs) in the network increases the short circuit level due to the short circuit current contribution of the DGs during faults. Compared to the synchronous and induction machine based generators the inverter based generators, such as Photovoltaic (PV) solar systems, contribute lower fault current to the network due to the characteristics of PV panels and inverter operation.

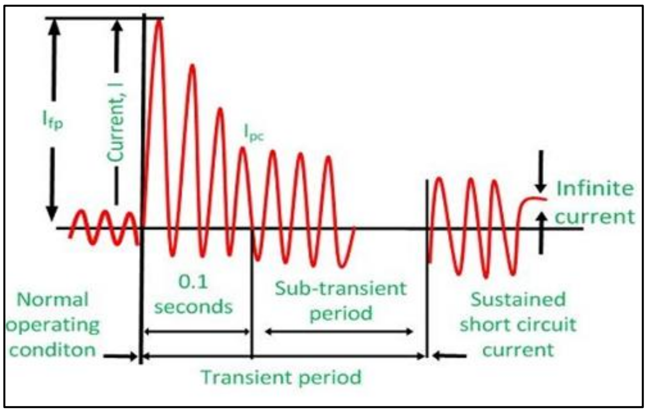

Fig. 1: Transient Behavior of Short Circuit Current

The short circuit current contribution from a PV system inverter is typically in the range of 1.2 times rated current for the large size inverter (1MW), 1.5 times (500 kW) for medium size inverter and between 2 - 3 times for smaller inverters. Although, each PV solar farm may contribute short currents as above, the total amount of fault current contribution may become unacceptably large for a feeder which has several PV systems connected. It is apprehended that short circuit current contributions from multiple solar systems in the distribution feeders may add up to levels that could be damaging to the circuit breakers. Hence circuit breakers will need to be upgraded and substations will need to be modified at significant cost to the utility.

II. Literature Survey

Adequate modeling of PV solar plants for predicting their short circuit contributions during network faults is essential. The traditional relay technologies mainly use overvoltage, under voltage and over current signals to detect the faults, and subsequently operate protective breakers. Continuous Wavelet Transform (CWT) has been used to process voltage and current transients for calculating the change in supply impedance. The occurrence of a grid fault can be identified within half a supply cycle and decision can be made if the fault requires a distributed generation unit to be disconnected [1].

A four-stage fault protection scheme against short-circuit fault for inverter based DGs is proposed in. The inverter is initially controlled as a voltage source, which changes to the current controlled mode upon detection of the fault, thereby limiting the inverter output current. A lab validated pilot protection system based on time-synchronized measurements of instantaneous currents is proposed in, that is capable of tripping the fault in less than half a cycle [2].

A concept of rate of change of current has been proposed as a minimum fault-current change limit to prevent nuisance current-limiter operation. The current slope signal di/dt is utilized to detect a grid fault and rapidly operate a Fault Current Limiter in less than half a cycle. So far, the above fast faults detection techniques have been used for protection of network and DGs; and for unsymmetrical fault detection in fault current limiters (FCL). However these techniques have not been used to prevent any short circuit current contribution in excess of the rated or utility-acceptable current output of PV solar inverters [3].

III. PROPOSED METHODOLOGY

This paper discusses about a new current detection module, which is introduced based on the rate of rise of current together with the current magnitude in a PV solar system based DG. This concept is derived from the patent [4]. In this module, the short circuit current is detected very rapidly and any of the following two control operations can be initiated, per the applicable grid code in that region.

One of the control operations discusses about the disconnection of the PV inverter before the current exceeds the rated output current of the inverter. The rapid disconnection of DG avert the fault current to rise beyond the utility allowable limits. Implementation of such a strategy potentially mitigates the problem of short circuit currents from PV solar systems which led to the delay or denial of their connectivity in regions such as in Ontario.

The objective of the proposed technique is not to detect the event of any fault in the network but only to recognize such fault conditions during which the inverter short circuit current is likely to exceed its rated magnitude. The intent is to disconnect the inverter as rapidly as possible, as soon it is predicted that the short circuit current will reach limits considered unacceptable by the interconnecting utility.

The second control operation proposes the transformation of the PV inverter into a dynamic reactive power compensator STATCOM and provide grid support functions. A new concept of utilizing PV solar farms as STATCOM (PV-STATCOM) both during nighttime and daytime for different grid support functions was introduced in. These functions include dynamic voltage support to increase the connectivity of neighboring wind farms; enhance power transmission capacity through power oscillation damping, etc. The short circuit current detection technique proposed in this paper can be utilized to shut down the real power generating function of the PV solar farm very rapidly in the event of a fault, and autonomously transform the PV solar farm into a STATCOM (PV-STATCOM) with full inverter capacity. This smart inverter control concepts is based in part on the pending patent.

The work presented in this paper considers a case study where a fault in the network causes a critical inductor motor load to get destabilized. These critical IM loads, in case of cessation; even for a short duration of few minutes, can indulge into a significant economic loss to the industrial facility using these IMs.

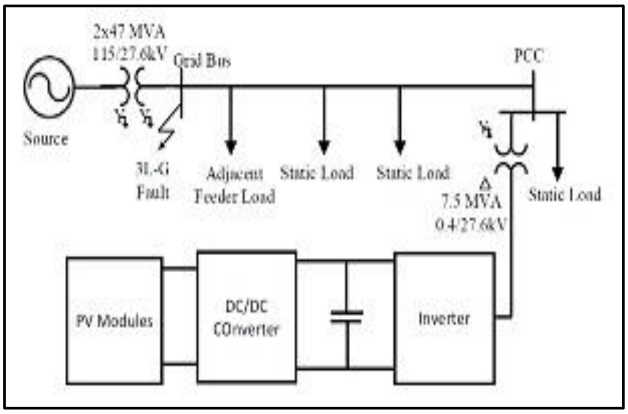

Fig. 2: System model of distribution network

The system model consider here is as shown in figure 2 which consists of a 27.6 kV feeder connecting the transmission network through a substation having two 47 MVA transformers. The equivalent source impedance is combined with the transformer impedance in the system model. The overhead lines and entire network is modelled in MATLAB 2009a software.

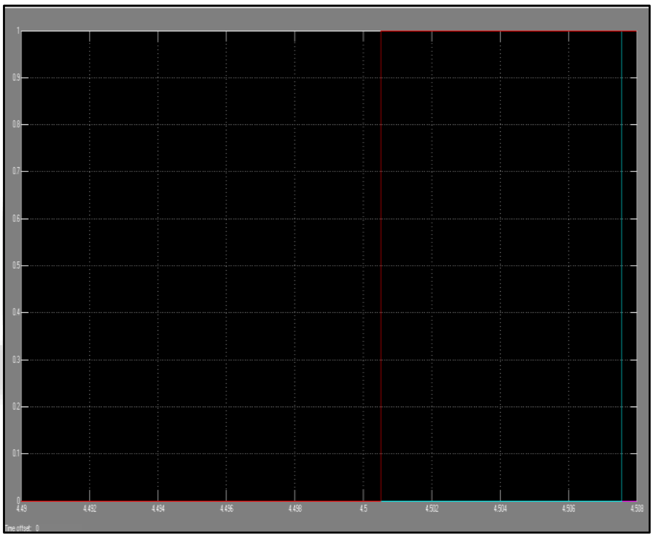

Fig. 3(a): Inverter fault current at PCC during LLG fault t = 4.5 s

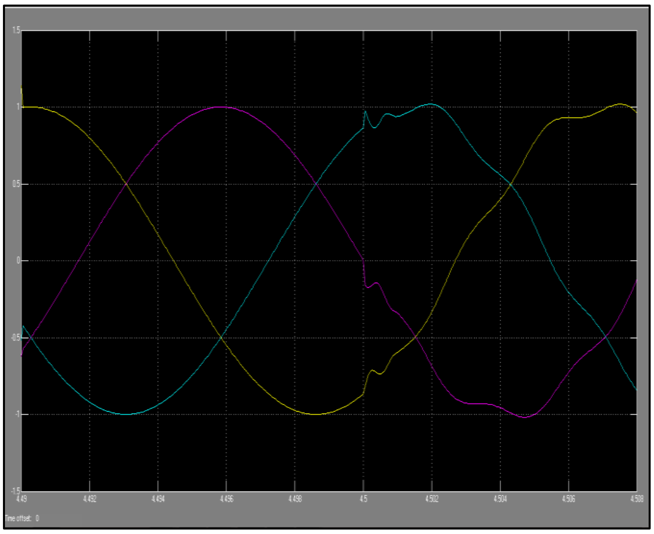

Fig. 3(b): Triggering signals

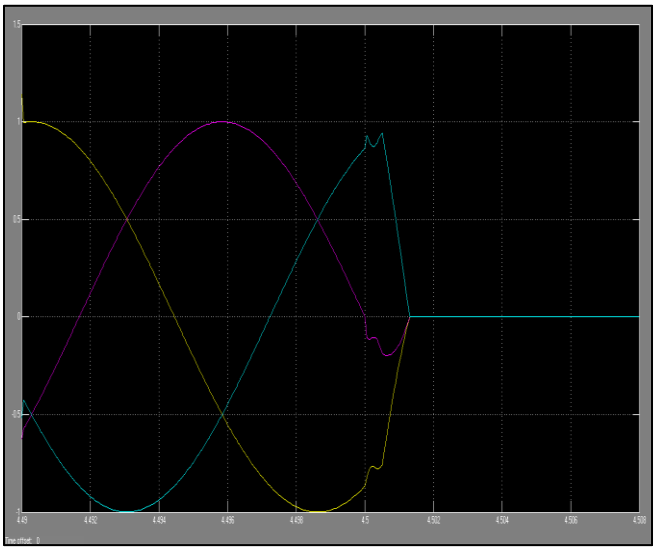

Fig. 3(c): Inverter fault current with proposed fault controller

A total distributed load of 15 MVA is modeled as three groups of fixed impedance three phase static loads connected to the feeder and a large load at the end of the feeder. The adjacent feeder load of 60MW at 0.9 pf. is modeled as a single aggregated P-Q load connected at the beginning of the feeder. A 7.5MW PV solar farm is connected near the end of the feeder. The proposed fault detection module is shown in figure 4.

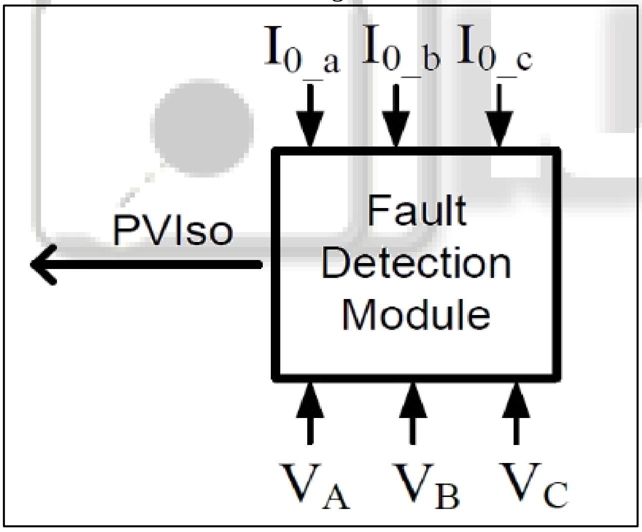

Fig. 4: Proposed Fault Detection Module

IV. SYSTEM DESCRIPTION

This module measures the instantaneous inverter output current and inverter terminal voltage. The measured instantaneous inverter output currents (I_{0_a}, I_{0_b}, I_{0_c}), are passed through a low pass filter to reject all the higher order harmonics or transients due to solar inverter injection, feeder capacitor switching or transformer energization. Subsequently the current signals are passed through two parallel paths in each channel; one path is through a slope detector (*d/dt*) and the other path is through a magnitude detector |*I*|.

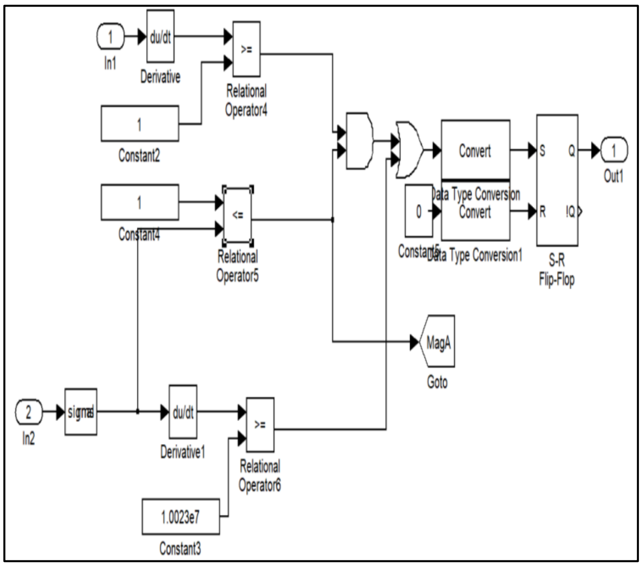

Fig. 5: Fault Detection Module

The slope detector is comprised of a comparator which compares the derivative of PCC current to determine the slope and compares with a reference slope (*d/dt*) max.

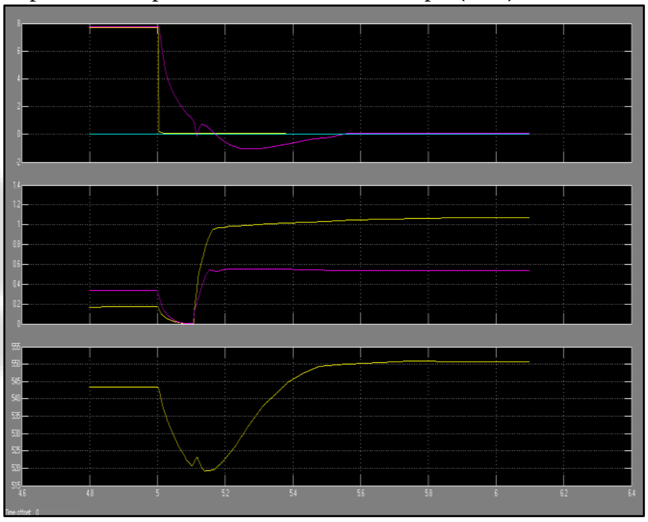

Fig. 5(a): Behaviour of Induction Motor Load after grid fault

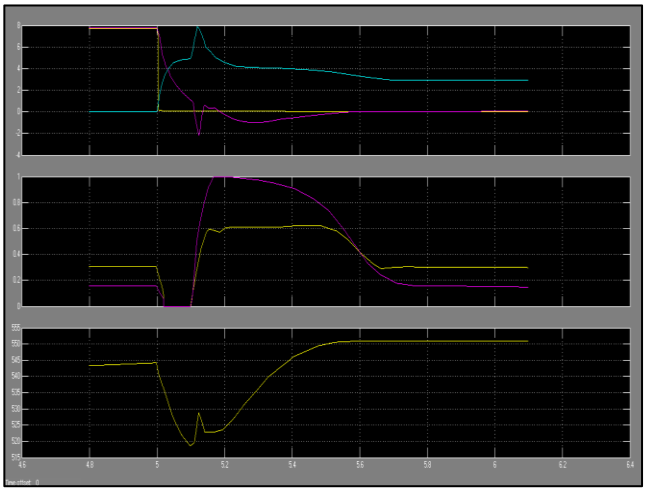

Fig. 5(b): Behaviour of Induction Motor with PV solar farm transformed into PV-STATCOM by the proposed short circuit current detector

For an inverter current $i = Imsin\omega t$, the reference slope or threshold limit can be determined approximately with the magnitude of (*d/dt*) of rated current as shown in the following expression;

$$|di/dt| \approx k\ \omega I^m \qquad (1)$$

Where, I_m is the peak magnitude of instantaneous inverter current, k is an arbitrarily selected tolerance constant (typically chosen to be 1.0 - 1.06) based on the maximum inverter current injection considered acceptable by the utility during normal operating conditions, and ϖ is the fundamental angular frequency. This technique is developed assuming that the PV solar farm has only one inverter and is connected directly to the PCC without any intervening cables or lines. The principles of this technique can be adapted to large solar farms with multiple inverters, which may be located at a distance from the PCC. In this case coordination of multiple inverters and delays in communication between measurements from the PCC to the individual inverters will need to be considered.

V. Conclusion

In this paper, a fast short circuit current detection technique is proposed for PV grid system. The proposed short circuit current detector is based on the evaluation of the slope and magnitude of the PV inverter current. When it detects short circuit fault in the circuit it perform following two operations depending upon the grid code:

1) Disconnect the PV inverter from the grid so that it does not cause any short circuit current injection into the grid, or
2) Autonomously transform the PV inverter into a dynamic reactive power compensator STATCOM.

The complete procedure of fault detection and further corresponding operation takes only 1-2 millisecond. While in circuit breaker relay operations it takes 10-20 milliseconds. So this technique detects short circuit fault in very less time and take further action action quickly.

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