FAST IDENTIFICATION METHOD FOR SHORT CIRCUIT CURRENT IN PV DISTRIBUTED GENERATOR

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ABSTRACT: In this paper, the PV-STATCOM is used to stabilize a critical induction motor load in the vicinity of the solar farm, which would have otherwise become unstable due to the grid fault. A new fast technique in which the slope of a PV inverter current is utilized to predict if the current is expected to exceed its rated value due to any grid faults is proposed in this paper. The objective was to prevent the loss of opportunity to integrate more PV based renewable generation. Two applications of this technique are demonstrated. In jurisdictions where grid codes require DGs to disconnect after a fault occurrence, such as in Ontario, Canada, this technique is utilized to rapidly disconnect the PV solar system even before the inverter short circuit current actually exceeds the rated current of the inverter thereby obviating the problem of any adverse short circuit current contribution into the grid. By using the simulation results we can demonstrate the effectiveness of this technique .

Index Terms— Photovoltaic (PV) systems, Distributed Generator (DG), Inverter, Short Circuit Current, Protection, STATCOM, PV-STATCOM, Flexible AC Transmission System (FACTS)

INTRODUCTION

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.

In electric power systems, integration of more Distribute Generators (DGs) in the network increases the short circuit level due to the short circuit current contribution of the DG during faults [1]. Compared to the synchronous an induction machine based generators the inverter base generators, such as Photovoltaic (PV) solar system contribute lower fault current to the network due to the characteristics of PV panels and inverter operation. The short circuit current contribution from a PV system inverter typically in the range of 1.2 times rated current for the large size inverter (1MW), 1.5 times (500kW) for medium size inverter and between 2 - 3 times for smaller inverters. Although, each PV solar farm may contribute short circuit currents as above, the total amount of fault current contribution may become unacceptably large for a feeder which has several PV systems connected.

The objective was to prevent the loss of opportunity to integrate more PV based renewable generation in the Ontario distribution systems. It is important to note that in Ontario, and in some other jurisdictions in Canada, it is required to disconnect the PV solar farms or any other DGs upon detection of fault on the system. It is therefore important to detect the faults rapidly, and either disconnect the DGs from the network or provide grid support functions e.g. LVRT, as quickly as possible, depending upon the prevalent grid code requirements.

As a first step, adequate modeling of PV solar plants for predicting their short circuit contributions during network faults. Continuous Wavelet Transform (CWT) has been used to process voltage and current transients for calculating the change in supply impedance. 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.

To prevent any short circuit current contribution these techniques have not been used in excess of the rated or utility-acceptable current output of PV solar inverters. 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: i) disconnect the PV inverter before the current exceeds the rated output current of the inverter.

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. ii) Transform the PV inverter into a dynamic reactive power compensator STATCOM and provide grid support functions. In this paper a case study is presented when a fault in the network causes a critical inductor motor load to get destabilized. The proposed technique does not disconnect the PV inverter.

SYSTEM MODEL

The study system is comprised of a typical realistic distribution network with a PV solar farm [33] as shown in Fig. 1.

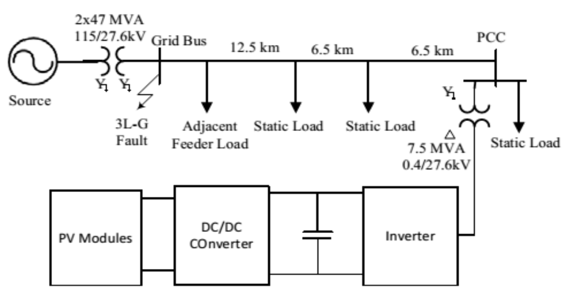

Fig. 1. One line diagram of the study system.

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.

B.PV System Model

Fig. 2 presents the detailed PV system model. The PV module in Fig. 2 (a), boost converter and inverter in Fig. 2 (b), AC filter in Fig. 2 (c), Maximum Power Point Tracking (MPPT) module in Fig. 2 (d) and the inverter controller in Fig. 2 (e) constitute the conventional PV solar farm system.

The PV module is modeled as DC voltage controlled DC current source. The boost converter and inverter along with its controller is used to transfer all the available power to the AC grid by regulating the DC voltage across the DC link capacitor with the use of DC link reference obtained from MPPT module. The boost converter performs the MPPT and inverter regulates DC link voltage. The inverter maintains unity power factor operation by regulating reactive power output to zero.

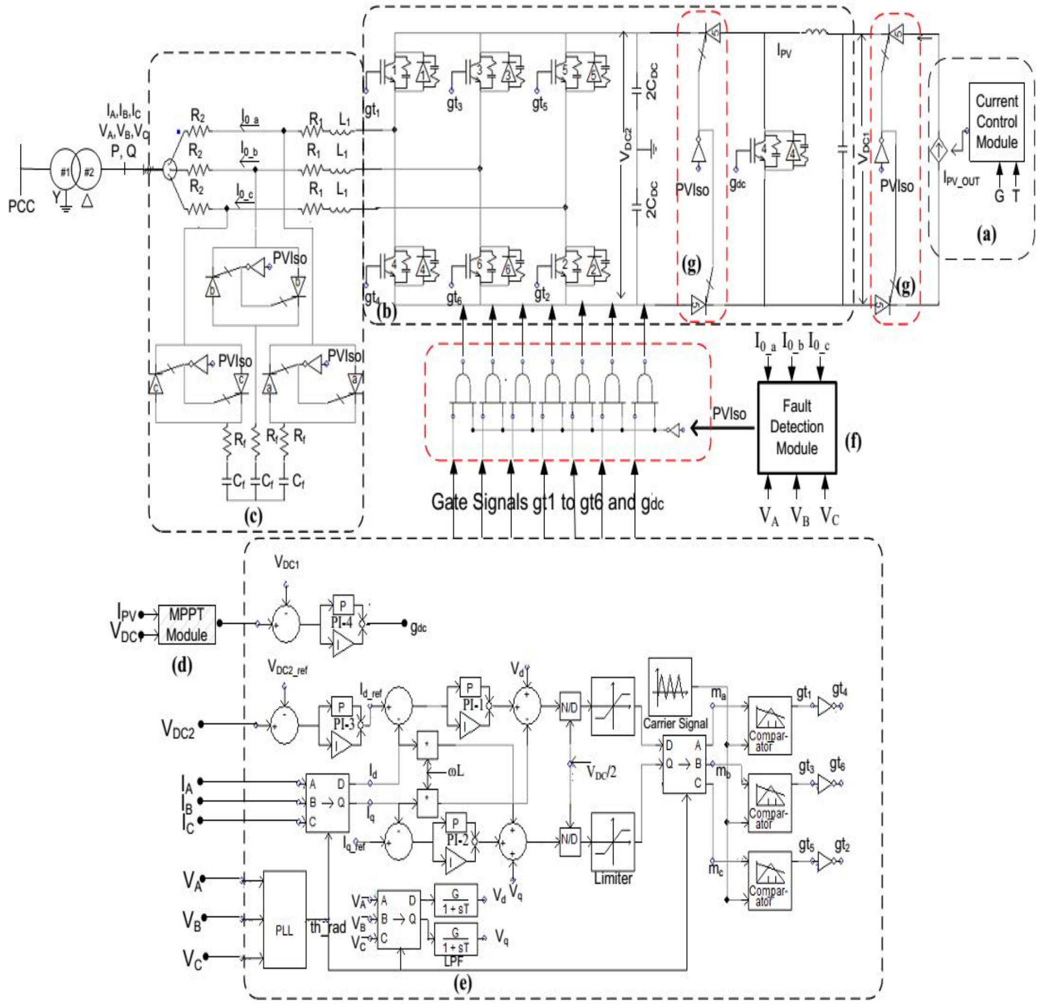

Fig. 2. Detailed PV system inverter and conventional controller with incorporated fault detection module.

The proposed fault detection module is shown in Fig. 2(f), and the internal circuit diagram of it is described in Fig 3.

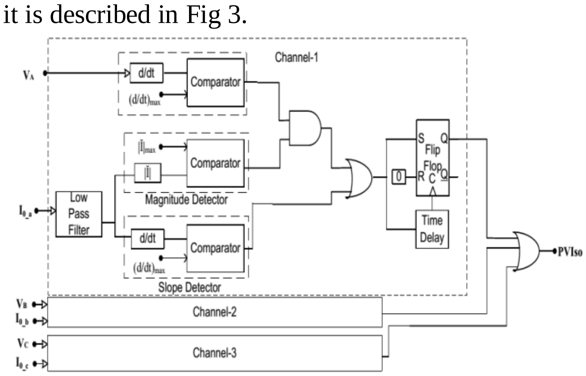

Fig. 3. Fault detection module

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. For an inverter current i = I msinωt, 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 [20].

$$|di/dt| \approx k\omega I_n \qquad (1)$$

where, Im 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 ω is the fundamental angular frequency.

In order to eliminate an unnecessary tripping of the inverters, the rate of change of voltage at inverter terminal is monitored. During a fault, the rate of change of voltage is higher compared to that during a large-load switching. The PV Iso signal is used to isolate the PV panel from the grid by using fast solid state switch as shown in Fig 2(g).

CASE STUDIES

Case studies are performed on the 7.5 MW PV solar system model as shown in Fig. 1 by applying different types of faults at PCC with proposed fault current controller enabled. The base value of a PV inverter current at PCC is 0.25 kA. Triga, Trigb, and Trigc are the outputs of slope detector from the proposed controller for phase A, B and C, respectively.

These conventions hold true for all PSCAD studies. The simulation results obtained from PSCAD are described below.

A. Symmetrical Fault

Fig. 4(a) demonstrates that the magnitude of inverter output current at PCC during line-to-line-to-line-to-ground (LLLG) fault at t = 2 second increases from 1 p.u. to 1.45 p.u.

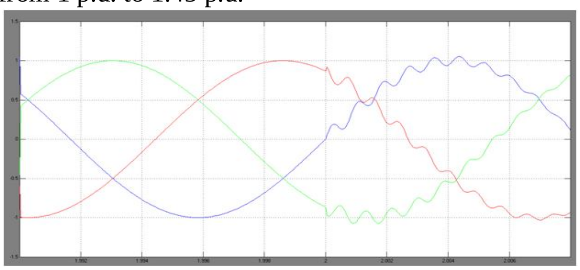

Fig. 6. (a) Inverter fault current at PCC during LLLG fault at t = 2 second

It is noticed from Fig. 6(b) that 'Trigc' signal becomes high within 0.3 ms from the initiation of fault in the grid, as slope of phase C (di/dt) has violated its permissible limit. Subsequently, Trigb and other triggering signals also get high.

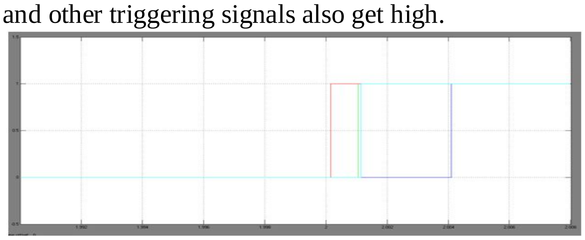

Fig. 6. (b) Triggering signals

However, the notable feature of the fault current controller is that only one triggering signal is needed to disconnect the PV inverter from the grid.

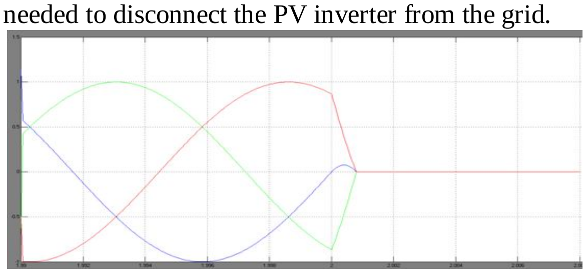

Fig. 6. (c) Inverter fault current with proposed fault controller

Fig. 6(c) portrays the inverter current with the proposed fault detector module activated.

B. Asymmetrical Fault

Fig. 7(a) depicts the inverter current after the occurrence of a single line-to-ground (SLG) fault at t = 2 second. The magnitude of inverter output current at PCC rises to 1.3 p.u.

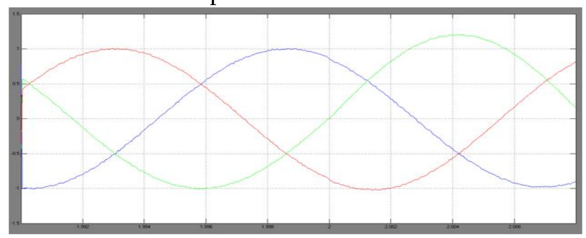

Fig. 7. (a) Inverter fault current at PCC during SLG fault at t =2 second

It is observed from Fig. 7(b) that 'Trigb' signal becomes high after 1.1 ms from the initiation of fault, as slope of phase B current has exceeded its maximum allowable limit.

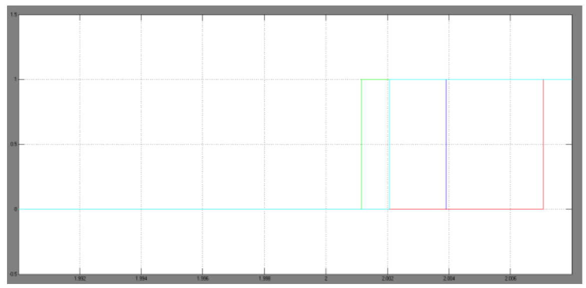

Fig. 7. (b) Triggering signals

As soon as the 'Trigb' signal becomes high, inverter fault current at PCC starts decreasing as shown in Fig. 7(c).

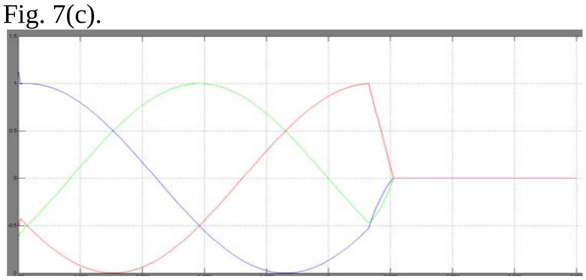

Fig. 7. (c) Inverter fault current with proposed fault controller

C. Different Faults at Different Time Instants

Fault studies are performed by applying different types of faults at different time instants and it is confirmed that the controller responds in the expected manner regardless of any type of fault at any time instant.

Fig.8(a) depicts that the magnitude of inverter output current at PCC increases from 1 p.u. to 1.45 p.u. during line to-line ground fault at t = 4.5 second.

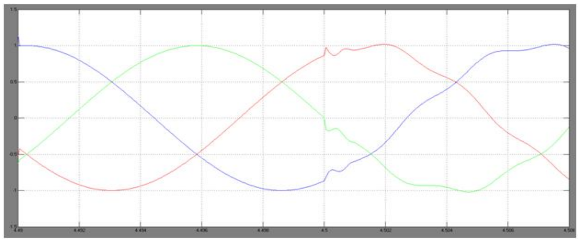

Fig. 6. (a) Inverter fault current at PCC during LLG fault at t = 4.5 second

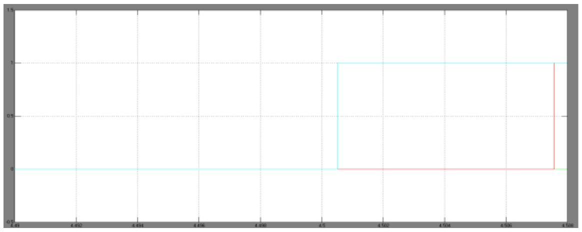

Fig. 8. (b) Triggering signals

Inverter fault current at PCC starts decreasing immediately upon detection of fault as shown in Fig. 8(c).

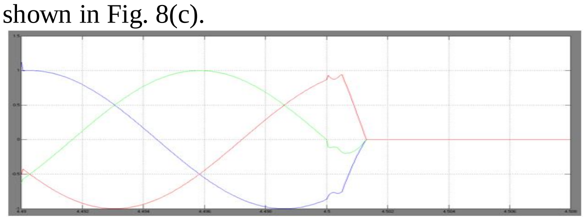

Fig. 8. (c) Inverter fault current with proposed fault controller

Therefore, there is no apprehension of any adverse short circuit current contribution from the PV inverter.

D. Load Switching

The performance of the controller is tested for two large load switching scenarios. Figs. 9 and 10 depict the inverter output and fault current detector signals for switching of 60 MVA static load and 25 MVA induction motor, respectively.

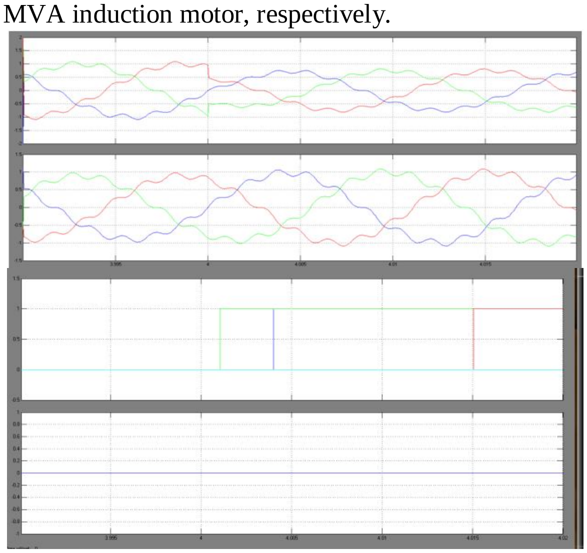

Fig. 9. Response of proposed controller for switching of 60 MVA static load at feeder end

The instantaneous output currents of the inverter are demonstrated

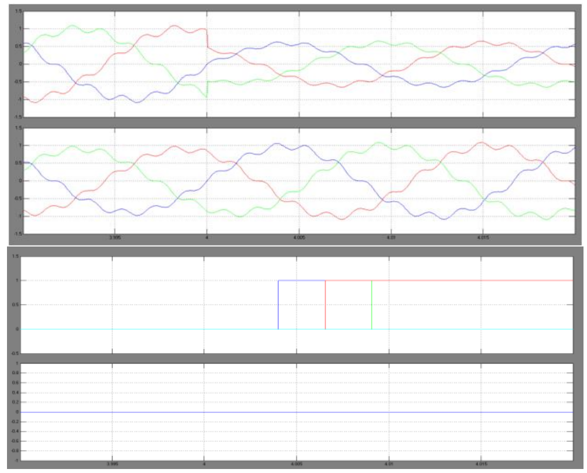

Fig. 10. Response of proposed controller for switching of 25 MVA induction motor load at feeder end.

The controller is also tested for its performance during the reclosure operation of a relay. Fig. 11 illustrates the inverter output and fault current controller response for fast reclosure operation of the relay.

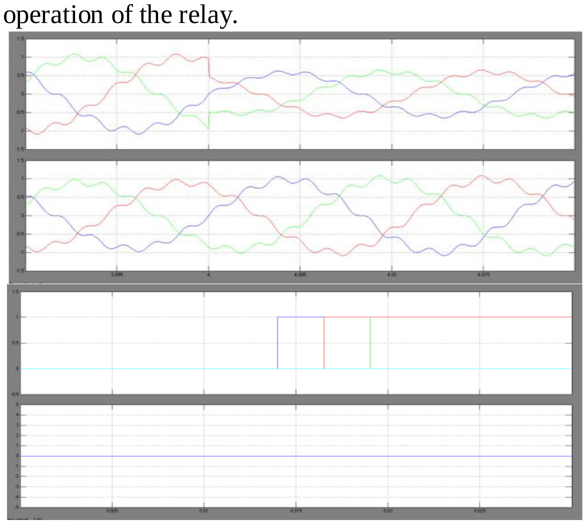

Fig. 11. Response of proposed controller for fast reclosure operation of relay.

Fig. 11 illustrates the inverter output and fault current controller response for fast reclosure operation of the relay. But similar to load switching, the rate of change of voltage is less than the reference value and thus the overall fault detector does not generate any tripping signal.

GRID VOLTAGE SUPPORT DURING FAULT

The application of the proposed short circuit current detector for providing rapid reactive power support to stabilize a critical induction motor. This application is especially relevant in jurisdictions where the grid codes require LVRT capability or a grid support function from DG inverters during faults.

As the IM is rated for lower voltage, a step down transformer (not shown in the one line diagram) is used to match the IM voltage ratings. The PV solar farm is connected at an intermediate location in the feeder, away from the induction motor.

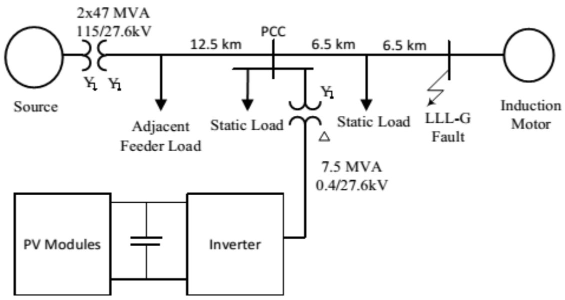

Fig. 10. Study System for PV solar farm operation as STATCOM for stabilizing critical induction motor load.

The PV-STATCOM controller is described. Due to space reasons the detailed description of the PV- STATCOM controller is not provided here, only its application in stabilizing the critical induction motor is presented.

A.**Case 1: Conventional PV System Disconnected During Fault**

Fig. 13 illustrates the IM response for a LLLG fault at motor terminal. The voltage at the IM terminal is illustrated in Fig. 13(a), IM speed is shown in Fig. 13(b).

DC power and real and reactive power generation by the PV solar farm are demonstrated in Fig. 13(c), the real and reactive power drawn by the IM are presented in Fig. 13(d), and DC link voltage is depicted in Fig.13(e).

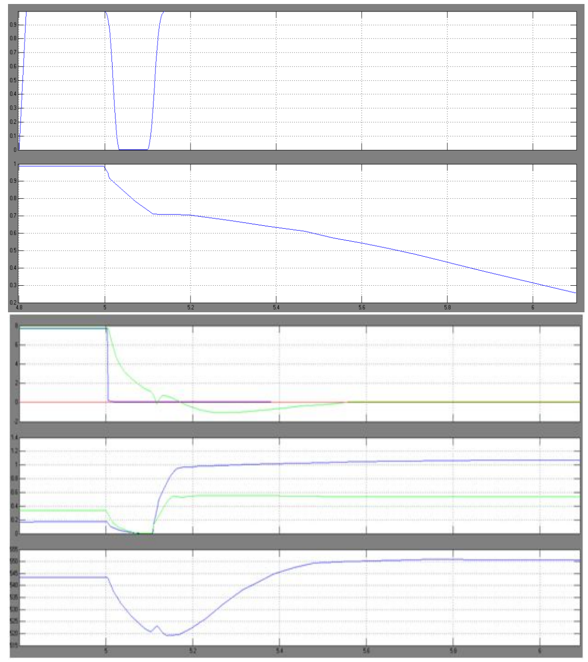

Fig. 13. Behaviour of Induction Motor Load after grid fault.

B. Case 2: PV System Operation as PV-STATCOM

Fig. 14 illustrates the IM response when the proposed short circuit current detector rapidly detects the fault and transforms the PV solar farm into a PV-STATCOM in PCC Voltage control mode of operation.

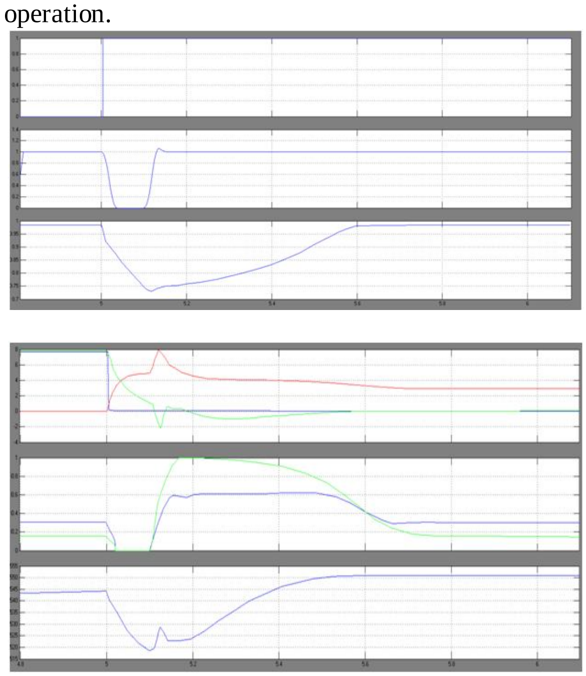

Fig. 14. Behaviour of Induction Motor with PV solar farm transformed into PV-STATCOM by the proposed short circuit current detector

The PV STATCOM immediately starts producing reactive power and provides voltage support to the grid thereby stabilizing the critical induction motor. The reactive power of the PV STATCOM eventually goes to zero after some time (which is not shown in the figure). The solar farm can autonomously transform back from PV-STATCOM mode to normal PV solar power generation mode after the motor is stabilized (although not demonstrated in this paper due to space limitation).

CONCLUSION

In this paper, a novel fast short circuit current detection technique is proposed for PV inverter based DGs. The technique can successfully discriminate between faults and large load switching and relay initiated operations. Among all the MPPT strategies, the incremental conductance technique is widely used due to the high tracking accuracy at steady state and good adaptability to the rapidly changing atmospheric conditions. This technique is general and can be applied on a PV solar system connected in any grid network. The objective of this technique is to facilitate PV solar farms in obtaining permission to get connected in substations or feeders which have already reached their short circuit current limits without the apprehension of additional short circuit current contribution from these solar farms. In this paper this fast fault detection technique is utilized to autonomously initiate a new control function of PV solar farm as a STATCOM (PV-STATCOM).

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