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An Improved Maximum Power Point Tracking Of Three Phase Grid Connected Based On Robust Nonlinear Controller

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***Abstract*: -- This paper presents a robust nonlinear controller design for a three-phase grid-connected photovoltaic (PV) system to control the current injected into the grid and the dc-link voltage for extracting maximum power from PV units. The controller is designed based on the partial feedback linearization approach, and the robustness of the proposed control scheme is ensured by considering structured uncertainties within the PV system model. An approach for modelling the uncertainties through the satisfaction of matching conditions is provided. The superiority of the proposed robust controller is demonstrated on a test system through simulation results under different system contingencies along with changes in atmospheric conditions. From the simulation results, it is evident that the robust controller provides excellent performance under various operating conditions**

***Index Terms* — Grid-connected PV system, matching conditions, partial feedback linearization, robust nonlinear controller, structured uncertainty.**

I. INTRODUCTION

In response to global concerns regarding the generation and delivery of electrical power, photovoltaic (PV) technologies are gaining popularity as a way of maintaining and improving living standards without harming the environment. To extract maximum power from the PV system [1], a robust controller is required to ensure maximum power-point tracking (MPPT) [1]–[3] and deliver it to the grid through the use of an inverter[4]–[6].Robustness is essential since the power output of PV units varies with changes in atmospheric conditions. Thus, the controller must be robust enough to provide a tighter switching scheme for the inverter to transfer maximum power into the grid over a wide range of operating conditions with a short transient period. In a grid-connected PV system, control objectives are met by using a pulse-width modulation (PWM) scheme based on two cascaded control loops[7].The two cascaded control loops consist of an outer voltage-control loop to track the maximum power point (MPP) and an inner current control loop to control the duty ratio for the generation of a sinusoidal output current which needs to be in phase with the grid voltage for unity power factor operation [7].The current loop is also responsible for maintaining power quality (PQ) and for current protection that has harmonic compensation. Linear controllers are widely used to operate PV systems at MPP [8]–[13]; however, most of these controllers do not account for the uncertainties in the PV system. Over the past few decades, one of the most important contributions in the field of control theory and applications has been the development of robust linear controllers for linear systems in the presence of uncertainties through the control scheme which is often obtained from linear matrix in equality (LMI) methods [14], [15]. A feed forward approach is proposed in [16] to control the current and dc-link voltage, and the robustness is assessed through modal analysis .A robust fuzzy-controlled PV inverter is presented in [17] for the stabilization of a grid-connected PV system where the robustness is achieved by using the Taguchi tuning algorithm. A minimax linear quadratic Gaussian (LQG) technique is proposed in [18] to design a robust controller for the integration of PV generation into the grid where the higher-order terms during the linearization are considered as modelling uncertainties. The controller design methods as presented in [8]–[13] and [16]– [18] are based online arized model so of nonlinear PV systems.In practice, PV sources are time varying, and the system is not linearizable around a unique operating point or a trajectory to achieve the desired performance over a wide range of changes in atmospheric conditions. To overcome the limitations of line are controllers ,an on linear proportional-integral-derivative (PID) controller based on the model prediction is presented in[19],where improved performance is reported. A Lyapunov based control scheme for a grid connected PV inverter is presented in [20] where an adaption law is included to improve the robustness. However, it is well known that the adaption technique is useful for systems with slow parameter variations which is not the case for PV systems as the changes occur rapidly. A sliding mode controller for a nonlinear g-connected PV system is proposed in [21] and [22] along with a new MPPT technique for providing robust tracking again uncertainties and unknown disturbances within the system. The performance of the sliding mode controller is confined to the sliding surface which is constructed from a linear combination of output injected errors. A feedback linearizing technique is proposed in [23] for PV applications where as uperfluous complex model of the inverter is considered to design the controller. To overcome the complexity, a simple and consistent inverter model is used in [24]. In [23] and [24], a feedback linear zing controller is designed by considering the dc-link voltage and quadrature -axis grid current as output variables .Power-balance relationships are considered to express the dynamics of the voltage across the dc-link capacitor. However, this relationship cannot capture nonlinear switching functions between the inverter input and output; to accurately represent a grid-connected PV system but it is essential to consider these switching actions. The current relationship between the input and output of the inverter can be written in terms of switching functions rather than the power balance equation .The voltage dynamics of the dc-link capacitor include nonlinearities due to the switching actions of the inverter. The inclusion of these nonlinearities will improve the accuracy of the PV system model; however, the grid-connected PV system will be partially rather than exactly linearized as shown in[25]. Although the approaches presented in ensure the MPP operation of the PV system, they do not account for inherent uncertainties in the system as well as the dynamics of the output filters. This paper aims to design a robust partial feedback linearizing controller where the robustness of the controller is ensured through the satisfaction of matching conditions. The stability of the internal dynamics of the PV system is discussed before deriving the proposed control law. Upper bounds are set on the modelling errors, which include both parametric and state-dependent uncertainties. The upper bounds on the uncertainties are such that the proposed controller guarantees stability and improved performance in the presence of all possible perturbations within the given bounds. Some directions about the implementation of the proposed controller are also discussed .The effectiveness of the proposed controller is tested for changes in atmospheric conditions as well as different system conditions, such as three-phase short-circuit faults and single-line-to-ground fault, and the results are compared with that of a partial feedback linearizing controller where robustness requirements are included in the design[25].

II. PROPOSED SYSTEM

2.1 PV SYSTEM MODEL:

A three-phase grid-connected PV system is shown in Fig. 1 where the PV array consists of a number of PV cells in a series and parallel combination to achieve the desired output voltage. The detailed modelling of a PV array and cell is given in [25]. The output voltage of the PV array is a dc voltage and, thus, the output dc power is stored in the dc-link capacitor .The output current of the PV array is and that of the dc-link capacitor is . The dc output power of the PV array is converted into ac power through the inverter. The inverter ,shown in Fig.1,is an insulated-gate bipolar transistor (IGBT)-based six-pulse bridge in a three-phase voltage source converter (VSC) configuration since the PV system is connected to a three-phase grid supply point. The main purpose of this paper is to design a robust switching scheme for the IGBT-based six pulse bridge so that the PV system is capable of providing maximum power into the grid. The extraction of maximum power from the PV unit can be confirmed by monitoring the dc-link voltage .

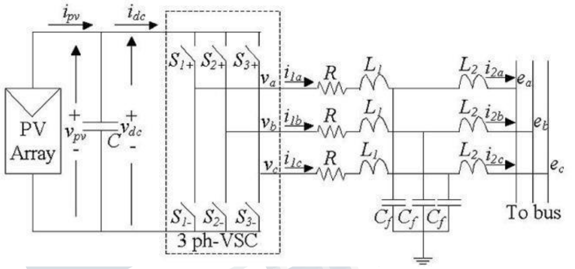


Figure 1: There-phase grid-connected PV system with an output filters.

The output ac power of the inverter is supplied to the grid through the filters and connecting lines where the resistance of the connecting line is and are the inductances of the filters and connecting lines, and the filter capacitance is . In Fig. 1, the grid voltages for phase , phase , and phase are ,and ,respectively. The extracted maximum power from the PV system will be supplied to the grid if the output current of the inverter remains in phase with the grid voltage and, thus, it is essential to control this output current. The state-space form of a three-grid-connected PV system without an filter is given in [25].In this section ,a detailed model of a three-phase grid-connected PV system is developed based on the schematic shown in Fig. 1.

$$i_{1a} = \frac{R}{L_1 \quad i_{1a}} - \frac{v_{cfa}}{L_1} + \frac{v_{PV}}{3L_1}\left(2K_a - K_b - K_c\right)$$

$$i_{1b} = \frac{R}{L_1 \quad i_b} - \frac{v_{cfb}}{L_1} + \frac{v_{PV}}{3L_1}\left(-K_a + 2K_b - K_c\right)$$

$$i_{1c} = \frac{R}{L_1 \quad i_{1c}} - \frac{v_{cfc}}{L_1} + \frac{v_{PV}}{3L_1}\left(-K_a - K_b + 2K_c\right)$$

By applying Kirchhoff’s current law (KCL) at the dc-link capacitor node, the following equation can be obtained:

$$v\cdot_{PV} = \frac{1}{C}\ i_{PV} - \frac{1}{C}(i_{1a}K_a + i_{1b}K_b + i_{1b}K_c$$

If KCL is applied at the node where the filter capacitor is connected, the following voltage–current relationships can be obtained

$$v_{cfa} = \frac{1}{C_f}(i_{1a} - i_{2a})$$

$$v_{cfb} = \frac{1}{C_f}(i_{1b} - i_{2b})$$

$$v_{cfc} = \frac{1}{C_f}(i_{1c} - i_{2c})$$

Finally by applying KVL at the grid-side loop, the state-space model can be written as

$$i_{2a} = \frac{1}{L_2}(v_{cfa} - e_a)$$

$$i_{2ab} = \frac{1}{L_2}(v_{cfb} - e_b)$$

$$i_{2c} = \frac{1}{L_2}(v_{cfc} - e_{cc})$$

Fig. 2. PLL model.

As mentioned earlier in this section ,the robust nonlinear control scheme needs to be designed in such a way that it is capable of controlling the dc-link voltage and the output current of the inverter. Since the component of the grid voltage is zero, the component current will not affect the maximum power delivery and it is essential to control the component current. From the mathematical model as represented by (7), it can be seen that the dynamics of the component output current of the filter do not have the relationship with the switching signals .But the dynamics of the inverter output current have a coupling with the switching signal and, therefore, is chosen as another control objective .An overview of designing the partial feedback linearizing controller is discussed in the following section by considering and as control objectives. As mentioned earlier in this section, the robust nonlinear control scheme needs to be designed in such away that it is capable of controlling the dc-link voltage and the output current of the inverter. Since the component of the grid voltage is zero, the component current will not affect the maximum power delivery and it is essential to control the component current. From the mathematical model as represented by (7), it can be seen that the dynamics of the component output current of the filter do not have the relationship with the switching signals .But the dynamics of the inverter output current have a coupling with the switching signal and ,therefore, is chosen as another control objective. An overview of designing the partial feedback linearizing controller is discussed in the following section by considering and as control objectives.

2.2 OVERVIEW OF FEEDBACK LINEARIZING THE CONTROLLER DESIGN

Since the three-phase grid-connected PV system, as represented by the group of , has two control inputs and the control needs to be designed with two control objectives

A. UNCERTAINTY MODELING

As mentioned earlier, the output power of the PV system depends on the intensity of the solar irradiation which is uncertain because of unpredictable changes in weather conditions .These changes may be modelled as uncertainties in current out of the solar panels which, in turn, causes uncertainties in the current (in the -frame, , and) injected into the grid. Since the uncertainty in the output power of inverters is related to the frequency of the grid, the proposed scheme has the capability of accounting for the uncertainty in the grid frequency. In addition, the parameters used in the PV model are, in most cases, either time varying or not exactly known and, therefore, parametric uncertainties exist too. Thus, it is essential to represent the uncertainties in PV system models.

III .ROBUST CONTROLLER DESIGN

The following steps are followed to design the robust controller for a three-phase grid-connected PV system as shown in Fig.

Step1:Partial feedback linearization of grid-connected PV systems. In this case, the partial feedback linearization for the system with uncertainties

$$v_1 = -1.36\omega_{i_{pv}} - 1.042\frac{R}{L_1}I_q - 1.23\frac{v_{cfq}}{L_1} + 1.18\frac{v_{pv}}{L_1}k_q$$

$$v_2 = \frac{1.16}{C}i_{pv}\ \frac{1.08}{C}I_{1d}K_d - \frac{1.14}{C}I_{1q}K_q$$

Step2:Stability of internal dynamics. In the previous step, the seventh-order PV system (7) is transformed into a second-order linear part (24), representing the linear dynamics of the system. For the transformed system ,the desired performance can be obtained through the implementation of a partial feedback linear zing controller. But before implementing such controllers, it is essential to analyze the dynamics of the nonlinear part represented by the state , (13) and the dynamics of which are called internal dynamics. To ensure stability of any feedback-linear zed system ,the control law needs to be chosen

$$\lim_{t\to 0} h_{i(x)\to 0}$$

Step3: Derivation of the robust control law. From (25), the control law can be obtained The performance of the designed robust stabilization scheme is evaluated and compared in the following section to that without any uncertainty as presented in [25] along with the direction of practical implementation.

$$K_d = \frac{0.85L}{v_{pv}} \left(\sim v_1 + 1.36\omega I_{1d} + \frac{1.042R}{L_1} I_{1q} + \frac{1.23 v_{cfq}}{L_1}\right)$$

$$K_q = -0.88 \frac{c}{I_q} \left[\sim v_1 + 1.16 \frac{i_{pv}}{c} - 1.08 \frac{I_{1d}}{c} K_d k_d\right]$$

IV .CONTROLLER PERFORMANCE EVALUATION:

To evaluate the performance of the three-phase grid-connected PV system with the designed robust controller, a PV array with 20 strings each characterized by a rated current of 2.8735 A is used. Each string is subdivided into 20 modules characterized by a rated voltage of 43.5 A and connected in series. The total output voltage of the PV array is 870 V, the output current is 57.47 A, and the total output power is 50kW. The value of the dc-link capacitor is 400 F ,the line resistance is 0.1 , and inductance is 10 mH. The grid voltage is 660 V and the frequency is 50 Hz. The switching frequency of the inverter is considered as 10 kHz. The inclusion of LCL filter dynamics affects the stability of the system for which a peak amplitude response at the resonance frequency of the LCL filter exists ,and if the parameters of LCL filters are not chosen appropriately ,the dynamic stability of the system will be degraded. To perform the simulation ,the inductor and capacitor values of the LCL filter are selected based on the filters design process as presented in [31] which are 10 mH and 3.1 F.

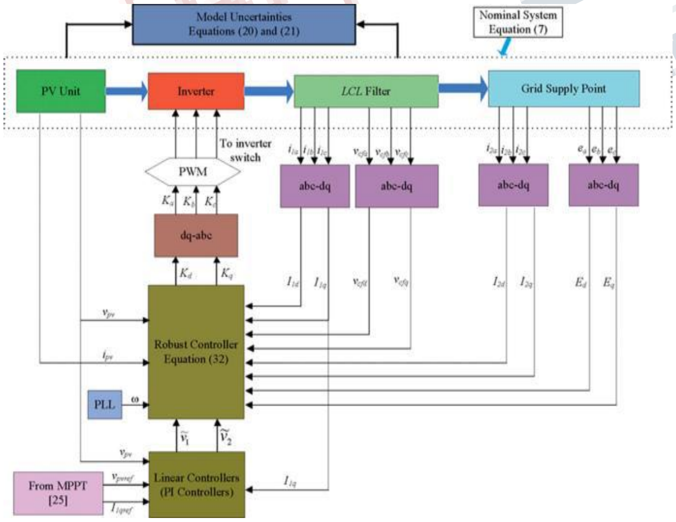


Figure .3: Implementation block diagram

The implementation block diagram of the designed robust control scheme is shown in Fig. 3 where the nominal model of the PV system is shown along with the uncertainties. From Fig. 3, it can also be seen that the output currents of the three phase inverter, voltages across the filter capacitor, output currents of the filter, and grid voltages are transformed into direct—and quadrature -axis components using transformation. Then, the control law is obtained in the frame and, finally ,reverse transformation (i.e.,) is done to implement the controller through the PWM. The designed scheme can also be implemented in a discrete time approach using digital signal processing and control engineering (dSPACE). To digitally implement the proposed scheme, it is essential to collect the data (output voltage and current of the PV array, output currents of the inverter and filter, voltage across the filter capacitor, grid voltage) from the PV system using different channels and convert these data through a dSPACE analog-to digital converter (ADC).The proposed algorithm needs to be developed in a Matlab Simulink platform, and the scheme needs to be built in dSPACE. To verify the feasibility of the proposed controller, different operating conditions have been considered. The performance of the controller is tested for the following scenarios: 1) standard atmospheric conditions; 2) changing atmospheric conditions; and 3) different types of short-circuit faults.

A. Controller Performance Under Standard Atmospheric Conditions

In this case study, the standard values of the solar irradiation(1kW)and environmental temperature (298K) are considered. Since the main control objective is to inject maximum power (50kW) into the grid ,the designed robust control scheme must be able to deliver this power into the grid by considering some uncertainties into the parameters and states of the system. To achieve this, the grid current and voltage remain in phase with each other which is already discussed in our previous work as presented in

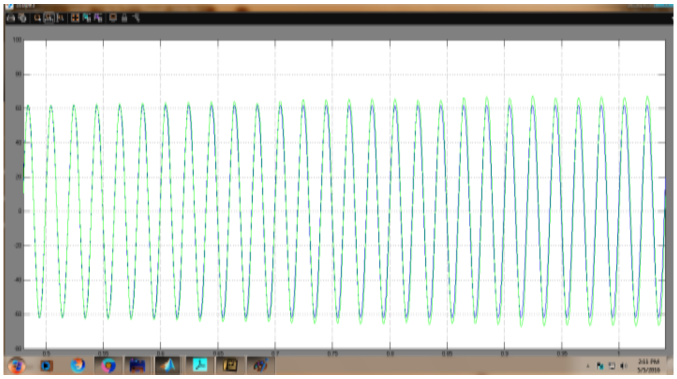


Fig.4 . Controller performance at standard atmospheric conditions.

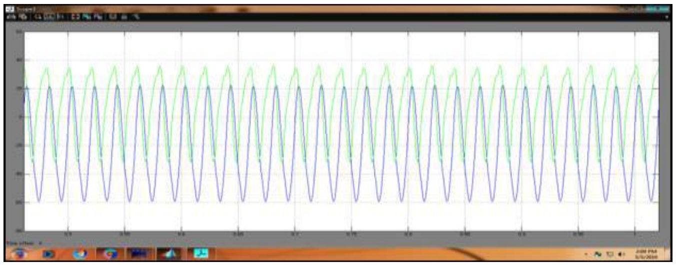


Fig. 5. Controller performance at changing atmospheric conditions.

But the robust partial feedback linearizing controller (RPFBLC) maintains the operation of the PV system at a unity power factor (red line).

B. Controller Performance Under Changing Atmospheric Condition:

At this stage ,it is considered that the PV unit operate under standard atmospheric conditions until1s.At 1s,theatmosphericconditionchangesinsuchawaythatthesolarirradiation of the PV unit reduces to 70% from the standard value

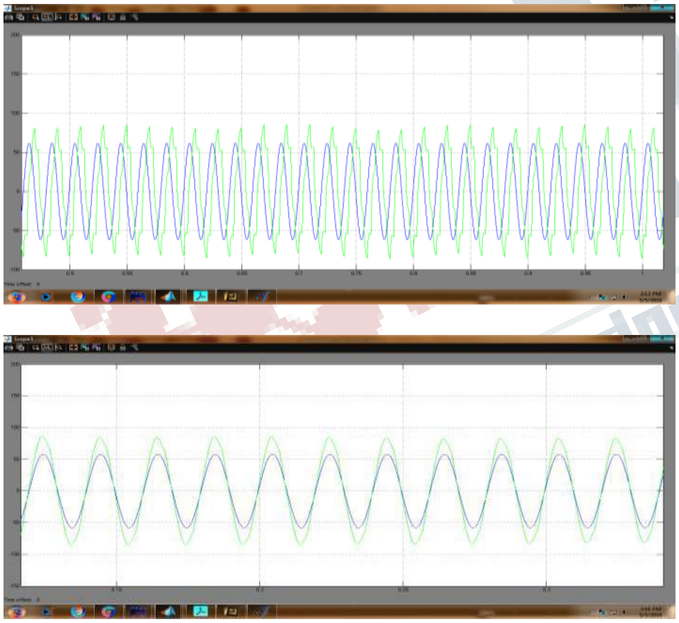


Fig.6. Controller performance during the three-phase short-circuit fault.

PV unit operates under the standard atmospheric condition up to 1.1 s and changing atmospheric conditions up to 1.2 s. After that, it operates under standard conditions ,and the designed controller maintains the operation of the system at unity power factor

C. Controller Performance During Short-Circuit Faults in the System

In this subsection, the robust performance of the controller is evaluated by applying a three-phase short circuit and single Fig line-to-ground fault at the output of the inverter .For both cases, the following fault sequence is considered: • fault occurs at 1.5 s; • fault is cleared at 1.6 s where the pre fault and post fault operations of the PV system are considered at standard atmospheric conditions. With this fault sequence, the following two cases are considered to evaluate the performance of the designed controller Case1) Controller performance with a three-phase short-circuit fault: In this case study, a three-phase short-circuit fault is applied at the output terminal of the inverter with the a aforementioned fault sequence. Since the current controller in the frame enables the appropriate current control in a balanced condition, the phase fault current generated by the PV inverter is limited by the reference values of -and -axis current.

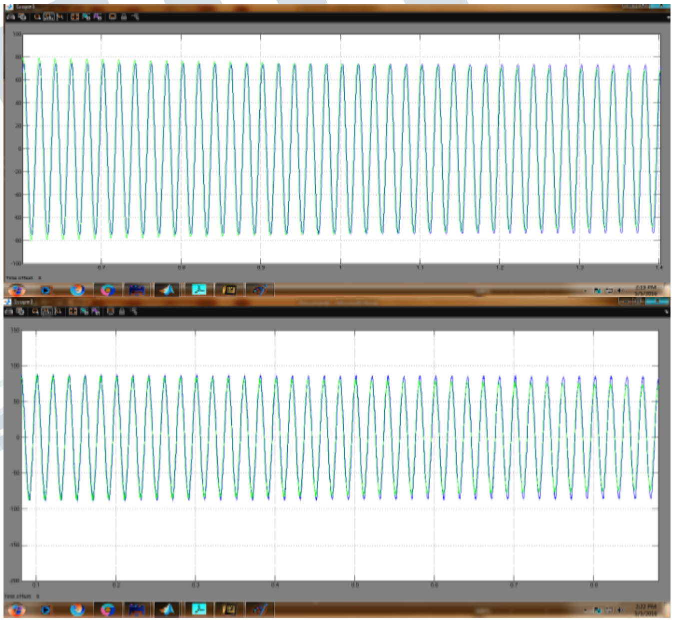
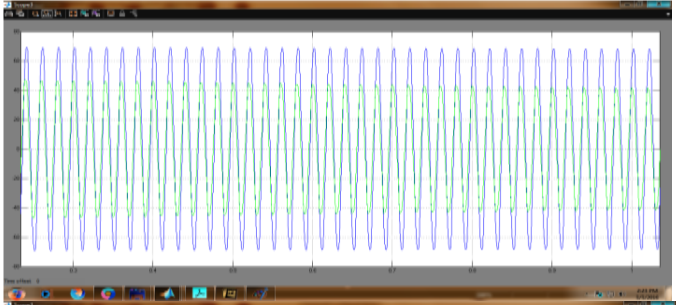
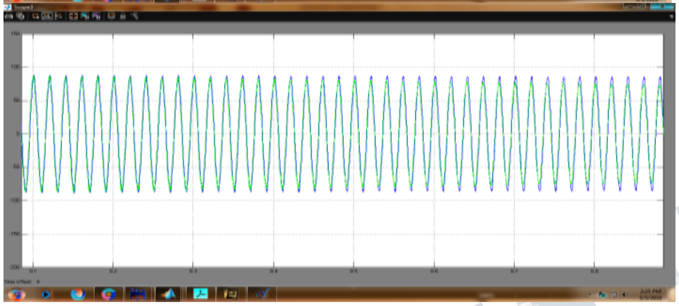


Fig. 7. Controller performance during thesingle-line-to-ground fault.

With the designed robust controller ,the post fault voltage and current are in phase as shown in Fig.6 (redline) .But there is still ap has difference between voltage and current, see Fig. 6 (green line) when the uncertainties are not considered in the controller design. Case2) Controller performance with a single line-to-ground fault. When a single-line-to-ground fault is applied at the output terminal of the inverter, there is a voltage imbalance due to the negative-sequence voltage component. Due to the stiffness of the grid, this voltage imbalance will also appear at the grid supply point [33]. In this situation, the proposed controller will inject negative-sequence current according to the principle of negative-sequence current injection as discussed in





In this case study ,a single-line-to-ground fault is applied between Phase and ground. The voltage of only phase will be reduced to zero and similarly the current of the same phase will increase upto the reference values

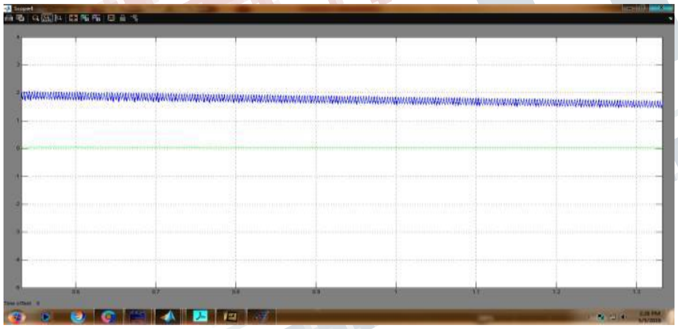


Fig.8.. Positive-sequence active and reactive current during the single-line-to-ground fault.

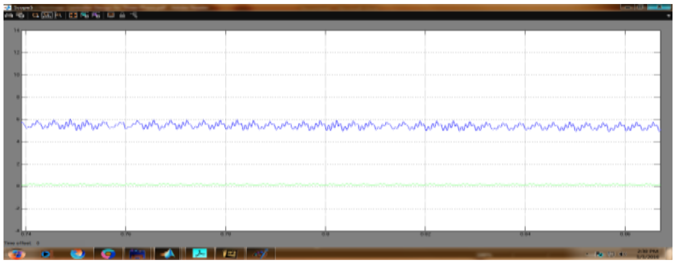


Fig. 9. Negative-sequence active and reactive power during the single-line-to-ground fault.

The resulting robust controller enhances the overall stability of a three-phase grid-connected PV system considering admissible network uncertainties. Thus, this controller has good robustness against the changes in parameters and variations in atmospheric conditions irrespective of the network parameters and configuration. Future work will include the implementation of the proposed control scheme on a practical system.

V.CONCLUSION

A robust controller is designed by modelling the uncertainties of a three-phase grid-connected PV system in a structured way based on the satisfaction of matching conditions to ensure the operation of the system at unity power factor .The partial feedback linearizing scheme is employed to obtain the robust control law and with the designed control scheme, only the upper bounds of the PV systems' parameters and states need to be known rather than network parameters, system operating points, or natures of the faults. The resulting robust controller enhances the overall stability of a three-phase grid-connected PV system considering admissible network uncertainties. Thus, this controller has good robustness against the changes in parameters and variations in atmospheric conditions irrespective of the network parameters and configuration. Future work will include the implementation of the proposed control scheme on a practical system.

REFERENCES

[1] S. Jain and V. Agarwal, "A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking," IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1928–1940, Sep. 2007.

[2] U. Zimmermann and M. Edoff, "A maximum power point tracker for long-term logging of PV module performance," IEEE J. Photo volt., vol. 2, no. 1, pp. 47–55, Jan. 2012.

[3] E. Koutroulis and F. Blaabjerg, "A new technique for tracking the global maximum power point of PV arrays operating under partial shading conditions," IEEE J. Photo volt., vol. 2, no. 2, pp. 184–190, Apr. 2012.

.

[4]S.B.Kjaer, J.K.Pedersen, and F.Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic

modules,” IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005.

[5]T.EsramandP.L.Chapman,“Comparisonofphotovoltaicarraymaximumpowerpointtrackingtechniques,”IEEETrans.EnergyConvers., vol. 22, no. 2, pp. 439–449, Jun. 2007.

[6]I.Houssamo, F.Locment ,and M.Sechilariu, “Maximum power point tracking for photovoltaic power system: Development and experimental comparison of two algorithms,” Renew. Energy, vol. 35, no. 10, pp. 2381–2387, Oct. 2010.

[7]F.Blaabjerg ,R.Teodorescu ,M.Liserre, and A.V.Timbus, “Over view of control and grid synchronization for distributed power generation systems,” IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006.

[8] A. Kotsopoulos, J. L. Darte, and M. A. M. Hendrix, “Predictive DC voltage control of single-phase pv inverters with small dc link capacitance, ”in Proc. IEEE Int. Symp .Ind .Electron.,Jun.2003,pp.793–797.

[9] C.Meza, J.J.Negroni, D.Biel, and F.Guinjoan,“Energy-balance modelling and discrete control for single-phase grid-connected PV central inverters,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2734–2743, Jul. 2008.

[10] R.Kadri ,J.P.Gaubert ,and G.Champenois, “An improved maximum power point tracking for photovoltaic grid-connected inverter based on voltage-oriented control,”IEEETrans.Ind.Electron.,vol.58,no.1,pp. 66–75, Jan. 2011.

[11] J. Selvaraj and N. A. Rahim, “Multilevel inverter for grid-connected PV system employing digital PI controller,”IEEE Trans. Ind. Electron., vol. 56, no. 1, pp. 149–158, Jan. 2009.

[12] N. A. Rahim, J. Selvaraj, and C. C. Krismadinata, “Hysteresis current control and sensor less MPPT for grid-connected photo voltaic systems ,”in Proc .IEEE Int .Symp .Ind .Electron.,2007,pp.572–577.

[13] A. Kotsopoulos, J. L. Duarte, and M. A. M. Hendrix, “A predictive control scheme for DC voltage and AC current in grid-connected photovoltaic inverters with minimum DC link capacitance,” inProc.27th Annu Conf .IEEE Ind.Electron.Soc.,2001,pp.1994–1999.

[14] M. Chilali and P. Gahinet,“-design with pole placement constraints An LMI approach, ”IEEE Trans. Autom. Control.

[15] K.Zhou and J.C.Doyle, Essentials of Robust Control. Upper Saddle River, NJ, USA: Prentice-Hall, 1998.

[16] A. Yazdani and P. P. Dash, “A control methodology and characterization of dynamics for a photovoltaic (PV) system interfaced with a distribution network,” IEEE Trans. Power Del., vol. 24, no. 3, pp. 1538–1551, Jul. 2009.

[17] Y.-K.Chen, C.-H.Yang, and Y.-C.Wu, “Robust fuzzy controlled photo voltaic power inverter with Taguchi method,” IEEE Trans. Aerosp. Electron. Syst., vol. 38, no. 3, pp. 940–954, Jul. 2009.

[18] M. J. Hossain, T. K. Saha, N. Mithulananthan, and H. R. Pota, “Robust control strategy for PV system integration in distribution systems,” Appl. Energy, vol. 99, pp. 355–362, Nov. 2012.

[19] L. Ma, F. Lin, X. You, and T. Q. Zheng, “Nonlinear PID control for three-phase PWM rectifier based on predictive current control,” in Proc.3rd IEEE Conf. Ind. Electron. Appl.,2008,pp.649–653.

[20]C.Meza, D.Biel, D.Jeltsema, and J.M.A.Scherpen, “Lyapunov-based control scheme for single-phase grid-connected PV central inverters,” IEEE Trans. Control Syst. Technol., vol. 20, no. 2, pp. 520–529, Mar. 2012.

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