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REAL-TIME SIMULATION ANALYSIS OF LM ALGORITHM-BASED NN FOR THE CONTROL OF VSC IN GRID CONNECTED PV-DIESEL MICROGRID USING OP4500 RT-LAB SIMULATOR

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Abstract

An effective and robust controller using Levenberg Marquardt (LM)-algorithm-based artificial neural network (ANN) controller to regulate the power flow in a photovoltaic (PV)-based generation is designed, implemented and validated in real time with OP4500 RT-Lab simulator. The controller functions as a regulator for voltage source converter (VSC), interfacing the PV source to the grid. Stable operation of VSC and microgrid system is the objective for both grid-connected and islanded operation characterizing the stability of the microgrid. The proposed ANN controller adaptively regulates the power outputs of the PV sources in accordance with the instantaneous power generation existing with other micro sources in the microgrid. The performance of the controller is investigated under varying irradiance and varying load conditions on both grid (AC load) and in the microgrid (DC load). Real-time information on the irradiance level is used to evaluate the performance of the controller in the microgrid. The robustness of the controller is tested in Opal-RT OP-4500 real-time simulator measurement considering solar irradiation for a day ranging between 2 am and 10 pm.

Key Words

Dynamic stability, diesel generator, photovoltaic (PV) panel, artificial neural network (ANN), microgrid (MG), voltage source converter (VSC), opal real-time simulator (Opal-RT)

1. Introduction

The current trend in electric power generation shifts to new era, where the power sources are located close to the loads utilizing renewable energy sources. This results in the minimization of transmission loss in the conventional power transmission and distribution network. These renewable power sources along with energy storage systems can be integrated with low-voltage distribution networks using suitable power electronic converter which are called distributed energy sources (DERs) and are referred as microgrids (MGs). The working of MG is dependent fully on the reliable operation of the power electronic interface converters that inject power from DER to the loads at the specifications determined by the loads/grid [1]. Hence the role of the controller is vital in enhancing the stability of the grid. A distributed optimal controller is presented to enhance the dynamic performance of the system in coordination with multiple distribution units in the MG which enhances the performance [2], [3]. An adaptive fractional fuzzy sliding mode controller is suggested for power management and load sharing in a grid-connected MG system. To obtain stable performance during load variations, fractional order-based sliding surface is considered and an adaptive fuzzy system is used to find the uncertain parameters [4]. A matrix variable-based modelling method is proposed for a distributed photovoltaic (PV) grid-connected system to study the stability issues of distributed maximum power point tracking-based system which consists of a large number of panel-level optimizers. The control parameters of grid-connected inverter and AC system strength are considered as the critical factors which affect the stability [5]. Genetic Algorithm (GA) optimization procedure is introduced in the dynamic switching process to improve the stability and dynamic performance under load disturbance in the MG. The optimal parameters influence the damping frequency of oscillatory components in transient response [6]. Based on the references [7]–[9], it has been observed that artificial neural network (ANN) controller is employed for the control within the MG as a standalone system. The ANN algorithm overcomes the inherent issues in improving transient performance and governing satisfactory power delivery to the grid during the excess generation in the MG and power reversal during a power deficit in the MG. The proposed controller functions as reference vector

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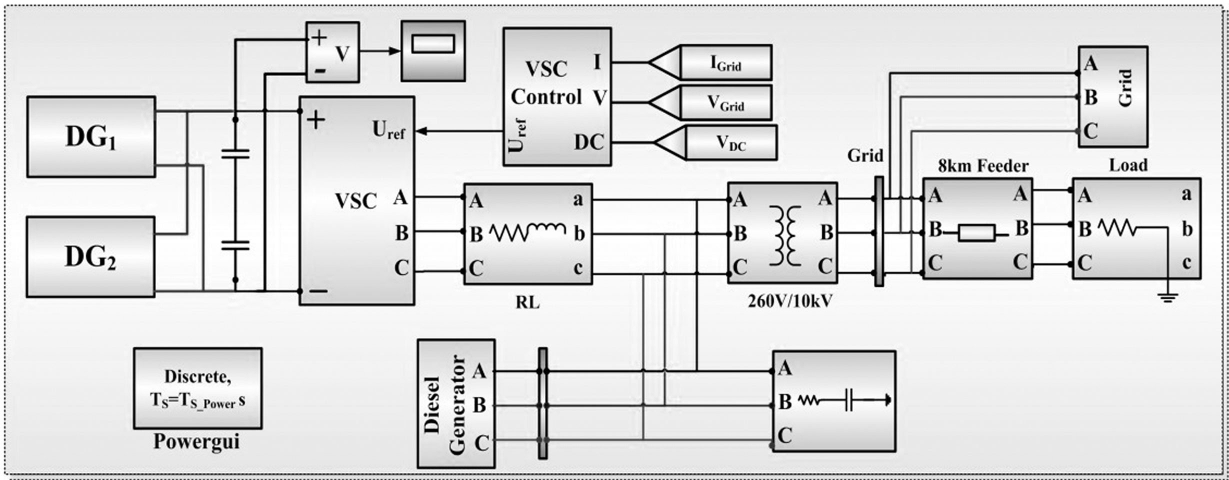


Figure 1. Simulink model of the proposed system.

generation for the voltage source converter (VSC). The major contribution of the work lies in applying the Levenberg Marquardt (LM) algorithm for dynamic power flow control in the grid-connected MG with changes in operating conditions. The performance of the controller is evaluated based on time response parameters against conventional Proportional plus Integral (PI) and Proportional plus Integral plus Derivative (PID) controllers. This paper is organized as follows. Section 2 presents the modeling of PV-diesel test MG in grid-connected mode. Section 3 discusses the design of proposed ANN controller. The implementation and validation of proposed control in RT-lab are discussed in Section 4, and Section 5 presents the conclusion.

2. Modeling of PV-Diesel Test Microgrid in Grid Connected Mode

The test MG is considered to have two PV sources and a diesel generator unit as shown in Figure 1. This MG is capable of operating in both islanded and grid-connected modes of operation. Loads connected are linear on either side. The power output of both PV sources is extracted using any available maximum power point tracking (MPPT) algorithm and pooled in the common dc-link, where a common VSC is present as grid interface. The VSC is coupled to grid either directly or *via* transformer of suitable rating. In the test MG, the VSC is transformer-coupled.

In the grid-connected mode, maximum power output from the PV sources is injected into the grid, whereas in the islanded mode, the DG sources supply only local loads. The excess power demand in the MG is met by drawing power from the grid, in case surplus power is exported to the grid. The diesel generator acts as the back-up source in the case of islanded mode and is self-governed by its governor. An additional dc-load is connected in the dc bus to analyse the power flow within the MG. The ANN controller controls only the VSC by taking the inputs as the grid voltage, dc-link voltage and VSC output current. An independent control loop is present to regulate the dc-link comprising of the PI controller. The technical specifications of the PV sources (DG1 and DG2) considered are available in [10] and diesel generator specifications [11]. The diesel engine output is mechanical power driving the synchronous generator. Motor inertia is considered along with the generator.

The transfer function of the diesel governor controller is expressed as

$$H_c = \frac{K\,(1+T_3)\times s}{(1+sT_1+T_1T_2s^2)} \tag{1}$$

The transfer function of the actuator is given by

$$H_a = \frac{1+sT_4}{[s(1+sT_5)(1+sT_6)]} \tag{2}$$

The power balance of the MG is satisfied when the PV plant is operating in grid-connected mode as well as in isolated mode. The power balance equation in the system under various loads and supply conditions is given in (3).

$$P_{pv} + P_{dg} + P_{grid} - P_{loss} = P_{load} \tag{3}$$

Where P_{pv} is the net PV output power, P_{dg} is the diesel generator power, P_{load} is the required load power and total power loss is considered as P_{loss} in the MG.

3. Design of the Proposed ANN Controller

ANN is the heart of the intelligent controller designed for the proposed work. ANN control is online, and it uses supervised learning method. The ANN controller receives information such as grid voltage, inverter output current and DC link reference voltage. The inputs to the ANN are the current references in *dq*-frame and the VSC output current transformed in *dq*-frame computed based on the real power generation from PV sources. The training data is then given as input for training using NN tool box in Simulink. The network configuration, learning algorithm must be fixed before training the data using the data set. The ANN is trained to monitor the real-time current outputs of VSC and generates the necessary modulating reference (V_{dq}^*).

The backpropagation (BP) training algorithm [12] and LM algorithm [13] are used in the network to train the data

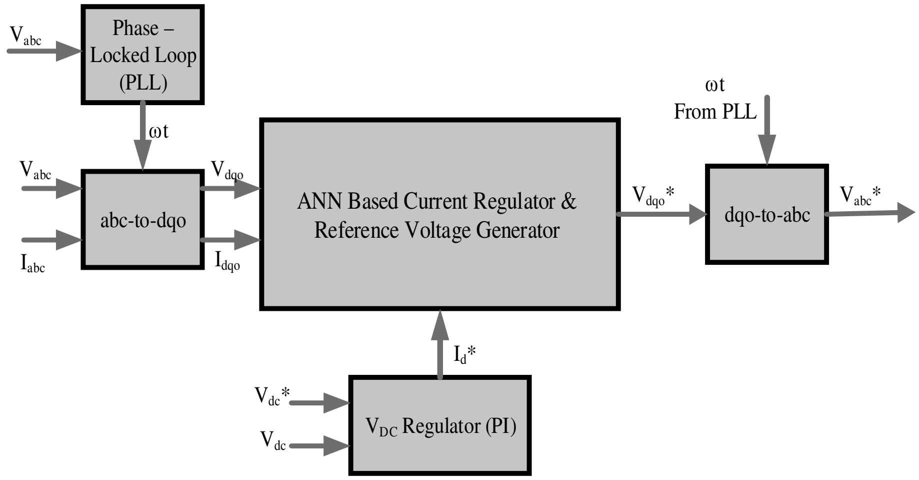


Figure 2. VSC control block.

set in the MG stability enhancement. The feedforward network is trained by the BP algorithm to train the ANN controller to get the optimum and best result. Based on the output obtained from the network, the optimal control pulses are generated for VSC and implemented in MATLAB platform. The proposed ANN control strategy is trained with the least mean square error of 0.025684 and regression value of 0.98163.

The structure of ANN-based VSC control is illustrated in Figure 2. The proposed technique estimates the parameters and calculates the error from the reference signal V_{dq}^{*}. According to the dq-control strategy, the error in dc-link voltage is regulated to deliver the desired charging current to maintain constant dc-link voltage. The ANN controller regulates the current delivered to the inverter based on available power output from PV and grid voltage.

4. Implementation and Validation of Proposed control in RT-Lab

The proposed ANN controller model is tested and analysed under two test cases, namely constant irradiance at varying load and varying irradiance at constant load. These test cases are further simulated with conventional PI and PID-based controller for comparison of results with the proposed controller. The parameters of the test-MG system considered for analysis are given in Table 1.

The implementation of the proposed system in the RT-Lab environment is shown in Figure 3. The test MG is dumped into OP4500 [14] target for implementation. The neural controller is implemented using NN Toolbox in Simulink. The system is then activated online executing the real-time control. The results of the study are scoped *via* analog output ports of OP4500 controller with suitable scaling.

4.1 Performance Analysis of the Proposed Controller

To prove the effectiveness of the proposed controller, two operating conditions are considered for analysis: Case-1 with constant irradiance to the PV and by varying load, and Case-2 with constant load with varying irradiance to the PV sources.

Table 1
Parameters of the Test Microgrid

Parameters	Values
DG-1 (PV)	115 kW
DG-2 (PV)	130 kW
DG-3 (DG set)	145 kW
Converter Structure	3ϕ-Bridge Inverter
Transformer	260/10 kV, 0.4 MVA
Load in microgrid side	440 kW
Grid Voltage	11 kV
Step load variation (microgrid)	70 kW

Case-1: Constant Irradiance from PV Generator and Load Variations

In this case, the irradiance input to the PV sources is set to 1,200W/m^2 for both the PV sources. A step-load variation is introduced on the grid at $t = 0.4$ s to 0.8 s on the grid side and a dc-load is switched on the dc-bus at $t = 0.4$ s. The power outputs of both PV sources and the diesel generator are evaluated. The real-time Opal-RT simulation for ANN controller performance of PV module in Case-1 is shown in Figure 4. The power output of PV is maintained stable irrespective of load changes, and the surge is attenuated by the grid and the dc-link capacitance. The power output of the diesel generator is shown in Figure 4(d) for reference.

Case-2: Irregular Irradiance from the PV Generator with Constant Load

With constant load on the grid, the irradiance is varied at a constant rate from 1,200 W/m^2 to 600 W/m^2 and again back to 1,200 W/m^2 in the time span of 0.4 s to

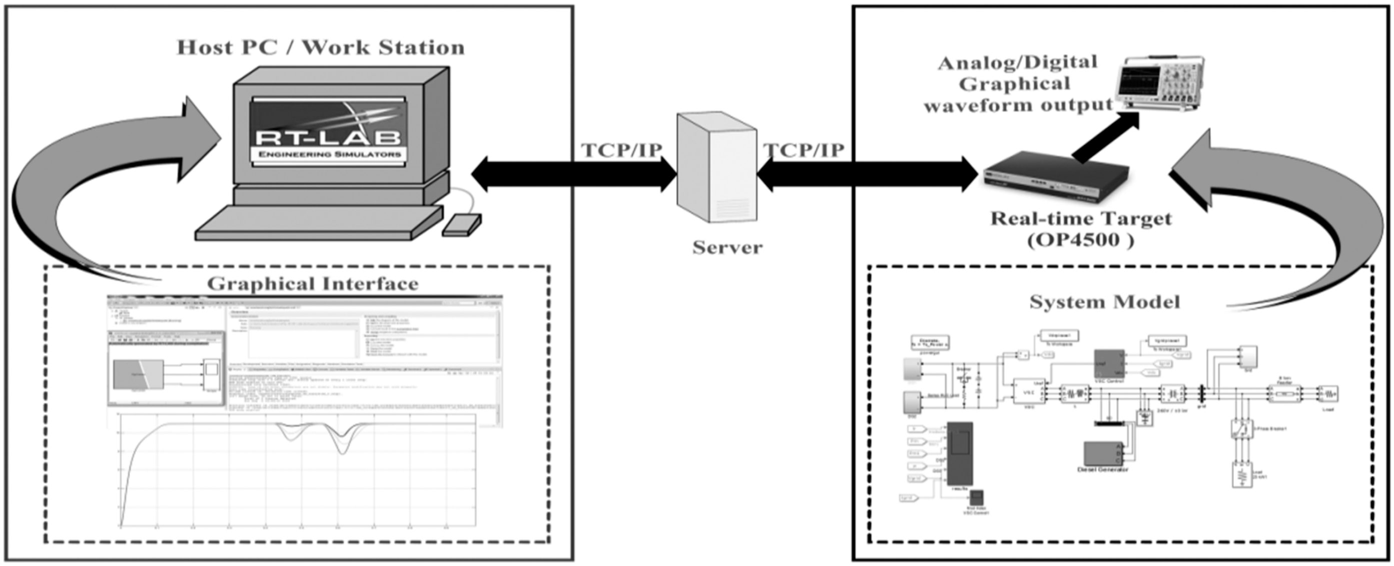


Figure 3. Real-time simulation connection with complete path of Opal-RT interface with Simulink system model.

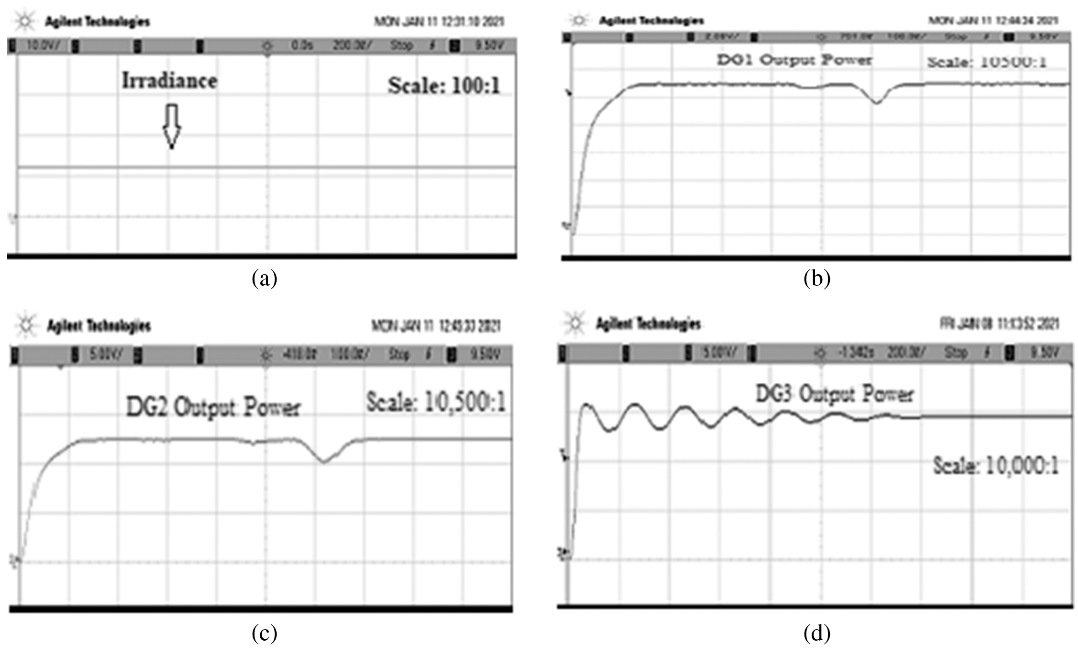


Figure 4. Outputs of OP4500 Simulator for Case-1: (a) Irradiance level; (b) DG1 output power; (c) DG2 output power; and (d) Output power of DG3.

both PV1 and PV2. The output power compensation is based on the proposed ANN controller to control the DG1, DG2, which maintains constant output with minimal disturbance. The real-time Opal RT simulation for ANN controller performance of PV module in Case-2 is shown in Figure 5 for asymmetrical irradiance variation. The result of real-time simulator is validated for this case.

4.2 Comparative Analysis of Proposed Controller with Conventional Controllers

The performance of the proposed LM-based ANN controller is compared with conventional PI and PID controllers subjected to the same operating conditions. The comparison is carried out to ensure the proper working and superior performance of the proposed controller in real time.

The real-time simulation output of the proposed controller for DG1 and DG2 is taken for comparison among the three controllers and is shown in Figures 6(a) and (b). The real power oscillations are damped and greatly minimized to 50% in comparison to the conventional controller, proving the superior performance of the proposed controller. It also marginally enhances the output power performance with 2%–4% in DG3 which is a mere sharing of load as in Figure 6(c).

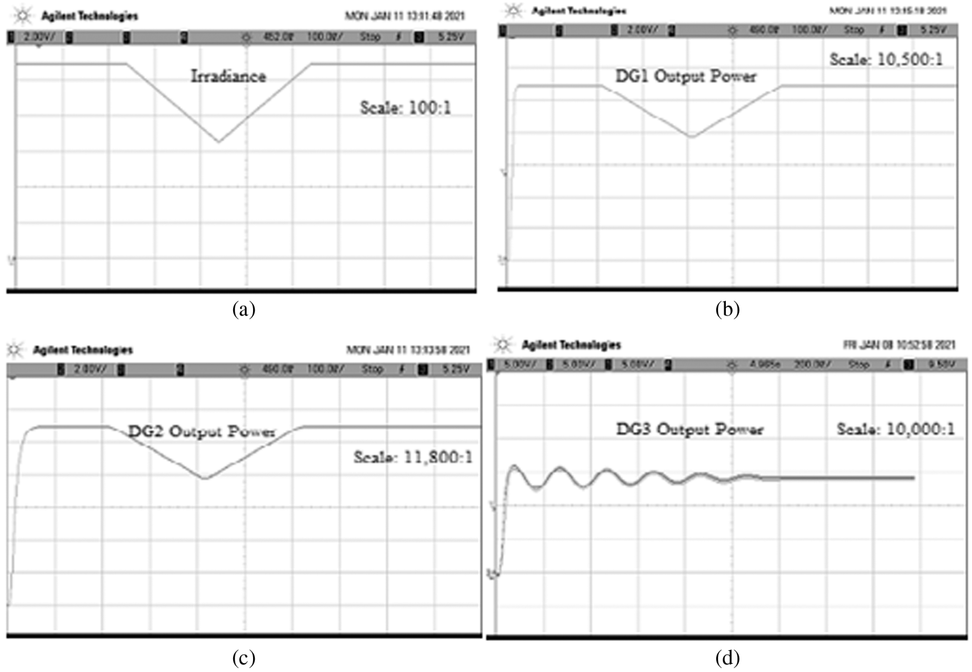


Figure 5. Real-time simulation in Opal RT for proposed ANN controller performance of PV module in Case-2 (a) Irradiance level; (b) DG1 output power; (c) DG2 output power; and (d) output power of DG3.

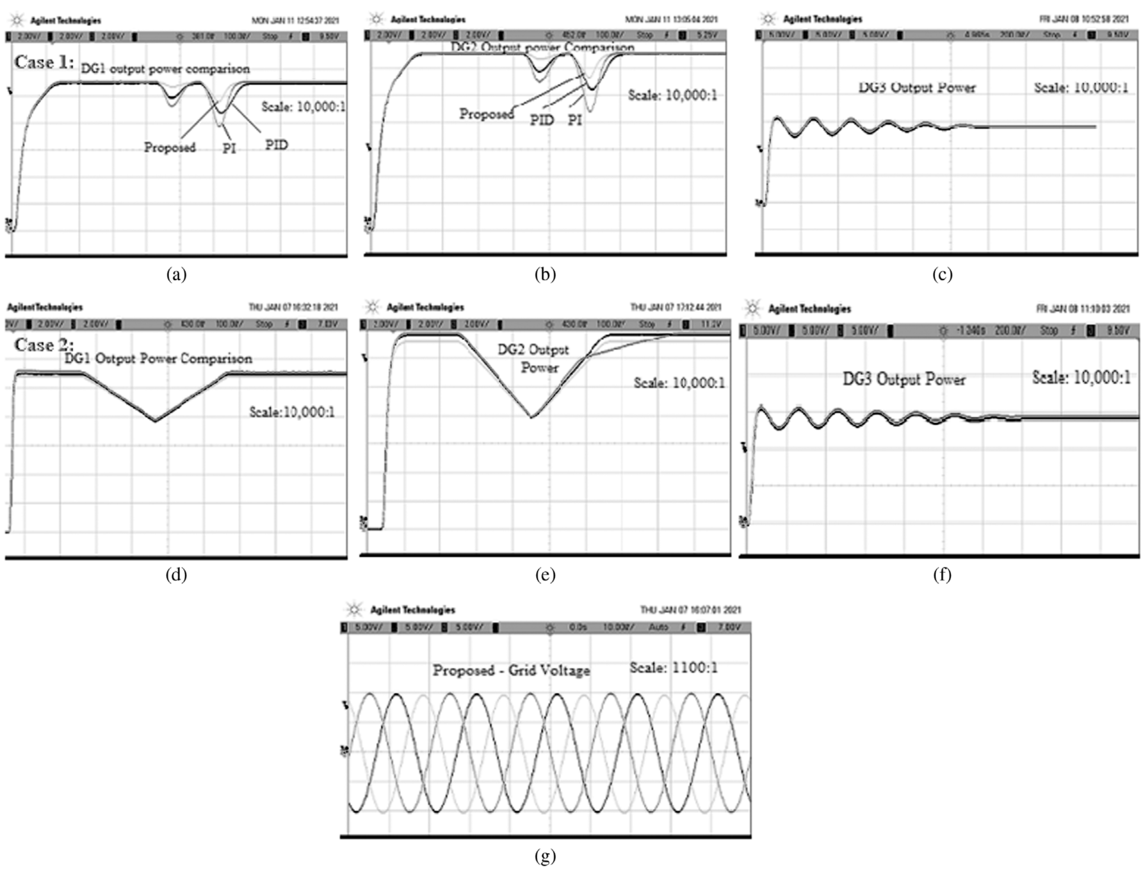
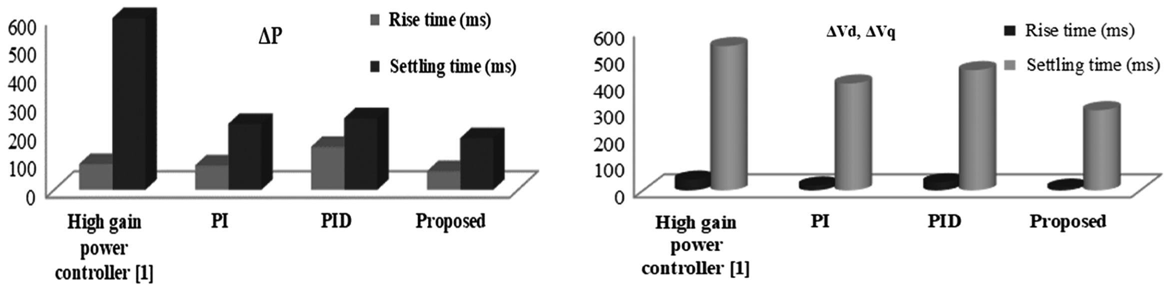
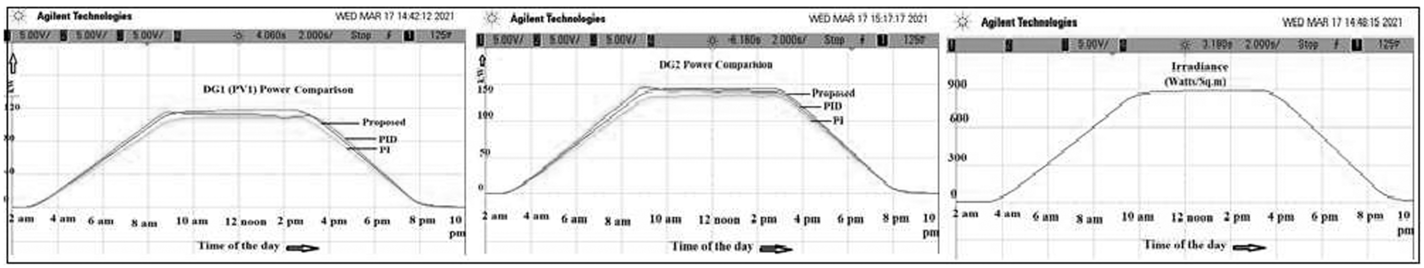


Figure 6. Opal RT real-time simulation for comparative analysis of Case-1 (a) output power of DG1; (b) output power of DG2; and (c) output power of DG3; Case-2 (a) output power of DG1; (b) output power of DG2; (c) output power of DG3; and (d) grid voltage.



(a) (b)

Figure 7. Comparison of the proposed controller performance against test system [1].



(a) (b) (c)

Figure 8. Real-time simulation in Opal RT for (a) irradiance variation for day time operation; (b) comparative analysis of DG1 output power; and (c) comparative analysis of DG2 output power.

Similar studies on the controllers were performed considering the Case-2 operation of the test MG. The results of the simulation are shown in Figure 6(d)–(f). The proposed controller provides a faster response of 0.6 s compared with the PI and PID controller and minimizes the power oscillations by 5%–10% to improve the output power. The grid voltage oscillation of the proposed controller is shown in Figure 6(g). The proposed controller also marginally enhances the output power performance with 2%–4% in DG3. Based on the above, it is clear that the proposed controller performs superior to the existing PI and PID controllers.

4.3 Performance Metrics for the Proposed ANN Controller

The performance of the controllers is analysed based on the time response parameters of the controller. Load disturbance is considered as a dynamic condition to evaluate the performance parameters in setting the reference voltage vectors (V_d, V_q) and real power oscillations (ΔP) from PV sources. The controllers are compared against rise time and settling time against the control parameters mentioned and depicted in converter loop damping [1] where a similar test system is considered. The results of the comparison are shown in Figure 7(a) and (b), respectively.

The real-time performance of the controller considering a day-long operation [15] is evaluated using Opal-RT simulation in DG1 and DG2 by taking solar irradiance between 2 a.m. and 10 p.m. The maximum solar irradiance (900 $\mathrm{W/m^2}$) is observed from morning 10 a.m. to evening 4 p.m. The results of the real-time simulator are shown in Figure 8(a), (b) and (c). The power output from DG1 and DG2 is more stabilized with the proposed control than in PI and PID controllers.

5. Conclusion

In this paper, an effective algorithm for regulating VSC operation under grid-connected mode employing LM-based ANN is proposed. The objective of real-time validation of the proposed controller is implemented with OP4500 real-time simulator. The performance of the proposed ANN-based VSC regulator was deeply analysed under two possible operating conditions, and the satisfactory performance was observed with the proposed control. The performance is validated numerically by considering time–response parameters of the test system and compared against a similar test system in [1] to prove the effectiveness. The results are compared against conventional PI and PID controllers in addition and to prove the flexible and adaptive nature of the proposed control. In all the cases, the proposed LM-based ANN controller performs superiorly and with satisfactory regulation of VSC in the MG. The net harmonic distortion in grid voltage is within the limit of 5% specified as per IEEE519:2014 under transient and steady-state operation.

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