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Controller Design to Enhance the Performance of a DC Microgrid Containing Solar PV Connected to the Main Grid

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ABSTRACT

This paper presents an effective design for a controlled DC microgrid power system that contains a solar photovoltaic (PV) connected to the grid. The main concept of this control system is to improve the operation of distributed generations (DGs) by keeping the balance between the active and reactive power requirements with other system components. The system includes a passive filter to improve the quality of both voltage and current signals. In addition, the maximum power from PV module is extracted by boosting the generated DC voltage to a suitable level. A voltage source inverter (VSI) is utilized to exchange the DC power to the AC grid. VSI controller consists of voltage and current control systems to regulate the output voltage amplitude and frequency as well as to control current waveform and the output power to the grid. This paper studies the effects of temperature and irradiance on the performance of the PV panel. The complete model of the system and its control is designed and implemented using the MATLAB–SIMULINK toolbox. The conventional PI controller is applied to control the system behavior in comparison with PID based Ziegler Nichol controller. The system is subjected to various disturbances such as 3-phase to ground fault and changes in irradiation and temperature. From simulation results, the system performance is enhanced with PID controller based Ziegler Nichol and is suggested to be the optimal controller for this DC microgrid system if it is well tuned.

Keywords: *DC Micro grid System, PV System, Maximum Power Point Tracking, PI Control, PID Control, Ziegler Nichol Method*

1. Introduction

Microgrid concept is considered the most important Microgrid concept is considered the most important part in the electric power industry. The objective of microgrid is to provide reliable, high quality electric power to the grid. The main feature of microgrid is the advanced structure that can facilate the connections of various AC and DC systems. DC microgrid is suitable method to combine a system of higher reliability and to reduce the losses of the system [1]. DC microgrid is suitable for domestic loads that are mainly DC loads, supplants DC supply and AC supply by using voltage source inverter (VSI) in to the grid. This paper describes DC microgrid that contains PV panel connected to the grid, maximum power point tracking (MPPT) is applied to track the maximum power generated by PV panel. Boost converter and VSI are used to convert DC to AC. VSI is a sort of inverters that converts DC to AC source and freely controlled AC voltage waveform [2]. A disturbance of change in irradiance and temperature is applied to study PV characteristics. Besides that, the study of the disturbance of change in irradiance and temperature is applied on the overall system. Also, a fault is applied on the system to determine the values of voltage and current at different points of the system during fault. Short circuit studies are essential design methods for appropriate protective schemes for various parts of the system from the abnormal conditions within minimum time where control systems are applied as protective scheme to save the system from abnormal conditions. Voltage control strategy for the microgrid with VSI depends on two control systems, which are current controller and voltage controller. Current controller controls the duty ratio and makes the response fast, while voltage control is necessary to provide the inductor current reference value and tracking voltage [3- 4]. Different controllers are applied by VSI such as PI controller and PID that are widely used in industrial applications due to their simplicity and ease of implementations. These controllers are used to improve steady-state error and in both, transient and steady state response. The PID controller parameter tuning process is an important issue for improving the

performance of the system. This paper describes the model of proposed DC/AC microgrid using MATLAB/SIMULINK. Also, parameters of PID controller are tuned by Ziegler Nichol method [5]. Finally, a comparison between the applied controllers (PI and PID) is presented to improve the system performance. The simulation results show that, the proposed PID based Ziegler Nichol controller provides enhanced performance for voltage profile and other system states [6].
This paper is organized as follows: Section (1) is an introduction, Section (2) shows DC microgrid modeling, Section (3) shows the control of system and Section (4) presents the simulation results.

2. DC Microgrid Modeling

Figure (1) shows the block diagram of DC microgrid system that contains PV panel coupled to the grid through boost converter. MPPT combines to DC/DC converter to produce the maximum power and inverter converts DC to AC [7]. The main objective of the overall system is to supplant AC power supply to the grid. Voltage control strategies for the microgrid, with VSI depends on two control systems, are current controller and voltage controller. The applied controllers are conventional controller (PI and PID). Ziegler Nichol method is proposed to tune the gains of controller to achieve the best performance.

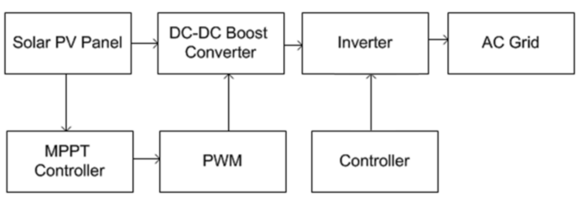


Figure 1- Block diagram of the studied system

The output voltage and current of the solar PV panel are fed as input of the MPPT controller to track the maximum generated power by the solar PV panel by adjusting the duty cycle [8]. The duty cycle is used to generate a pulse width modulation (PWM) signal to the boost converter. DC-DC converter boosts its input voltage value to the required voltage level and the output power. However, inverter converts DC to AC that supplants it the grid. The controller is applied by VSI to control the output power and the voltage that makes the response fast [9- 10]. The components of the studied system are described as follows.

2.1 PV array modeling

PV panel is modeled according to output current from the PV model. This model is equipped with MPPT control technique to produce the maximum output power and to operate the system at maximum efficiency under changing solar irradiance value and the operating PV cell temperature [11- 12]. The output current of the PV panel is calculated as [13]:

$$I_{pv} = n_p I_{ph} - n_p I_{sat} * \left[\exp\left(\left(\frac{q}{AKT}\right)\left(\frac{V_{pv}}{n_s} + I_{pv}R_s\right)\right) - 1\right] \qquad (1)$$

$$I_{ph} = \left(I_{sc} + K_i(T - T_r)\right) * \frac{G}{1000} \qquad (2)$$

$$I_{sat} = I_s * \left(\frac{T}{T_r}\right)^3 exp\left(\frac{qE_g}{KA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \qquad (3)$$

Figure (2) shows the equivalent circuit of a PV panel with a DC load.

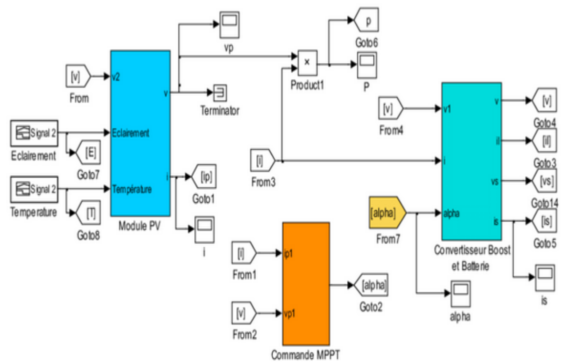


Figure 2- Model of the PV system

2.2 DC-DC Boost converter

Boost converter consists of a voltage source, an inductor, diode, insulated gate bipolar transistor switch and capacitor. This converter steps up the DC output power with associate degree larger than its input power and increases the DC input voltage to the required output voltage level as shown in figure (3). The boost converter is controlled by MPPT control technique which generates the switch control signal [13- 15].

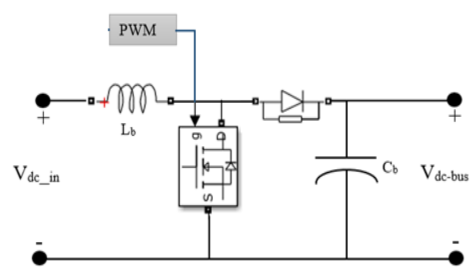


Figure 3- DC-DC boost converter

2.3 Maximum power point tracking (MPPT)

MPPT control is combined to boost converter that allows PV to produce the maximum power. MPPT is applied to track the maximum power generated by PV panel as shown in figure (4). Also, normally the efficiency of PV isn't very high so, MPPT is used to operate solar panel at maximum possible efficiency at any given solar irradiation and operating temperature [16].

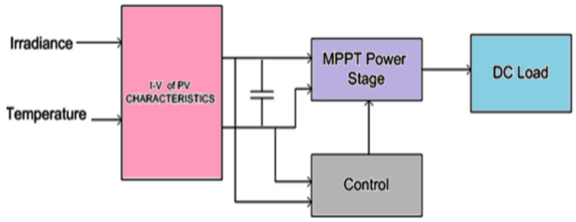


Figure 4- Block diagram of the MPPT

3. Control System Design

Block diagram shows voltage control strategy of microgrid with VSI as in figure (5). The shown block consists of two closed-loop systems control the voltage amplitude and frequency of the microgrid. A current controller in the inner control loop acts on the duty ratio in VSI switches by using PWM to make the response faster. A voltage controller in the outer control loop provides the inductor current reference value and tracking voltage. The inductor feedback current is compared with reference settings of the current and produces a duty ratio. The duty ratio is required to achieve better voltage tracking. Also, these loops are used to transmit the modulation index for the PWM generation to obtain the pulses which is used to operate the DC-AC inverter [17- 21].

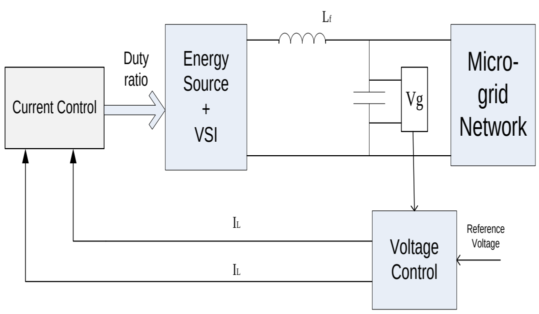


Figure 5- Inverter control diagram

The VSI converts DC to AC power supply that supplants to the grid. The applied controllers on VSI control the output power and the voltage to make the fast response. In this study, the applied controllers are PI and PID. The second control method uses Ziegler–Nichol to tune the parameters of PID controllers.

3.1 PI and PID controllers

Conventional PI controllers consist of proportional gain; k_p and integral gain; k_i, while PID controller consists of three gains which proportional gain; k_p, integral gain; k_i and derivative gain; k_d. Proportional term improves the transient response of the system and integral term decreases the steady-state error, while derivative term decreases the overshoot of the system. However, these controllers are tuned random, so these controllers are not achieved the optimal performance of the system. Ziegler–Nichol method is proposed to tune the gains of PID controllers.

3.2 Ziegler–Nichol method

The tuning method is the Ziegler Nichol, which simply and efficiently produces the optimal values of the three gains of PID controller. The advantages of this method are to provide lower percentage of overshoot and settling time to achieve better performance of the studied system. The implemented technique results in a 25% overshoot of the closed loop system. Controller gains are specified as given in Table (1).

The following steps are carried out to tune a PID controller by Ziegler–Nichol method [22]:

i) Set both integer and derivative gains to zero.
ii) Increase proportional gain, k_p from until reach critical value.
iii) Proportional gain equals critical gain k_{cr} that generates sustained oscillations.
iv) Gain value of k_{cr} and the resultant period of sustained oscillation are the critical time (p_{cr}).

Table 1- Controller gains by Ziegler–Nichol method

Controller	k_p	t_i	t_d
PI	$0.45\,k_{cr}$	$0.833\,p_{cr}$	0
PID	$0.6\,k_{cr}$	$0.5\,p_{cr}$	$0.125\,p_{cr}$

4. Simulation Results

Figure (6) shows the block diagram of the DC microgrid, this model presents the simulated responses of the studied system for the different operating conditions using the MATLAB–SIMULINK toolbox. The model describes DC microgrid consisting of PV panels connected to the grid through DC-DC boost converter and inverter. In addition, the VSI consists of current controller and voltage controller. The controllers are applied through voltage source control to control the voltage of the grid and the generated power from the system.

The study-case system is examined and tested for two case studies as following.

Case 1:

Figure (7) shows a comparison between PI and PID based Ziegler Nichol method on the system output when a 3-phase to ground fault occurs at the terminal of the grid where the fault is applied at t= 1.0 sec and cleared after t=1.5 sec. The system output is represented by active power, voltage and duty cycle. This fault condition occurs without any effect on irradiance (1000 w/m^2) or temperature (25 ºC)

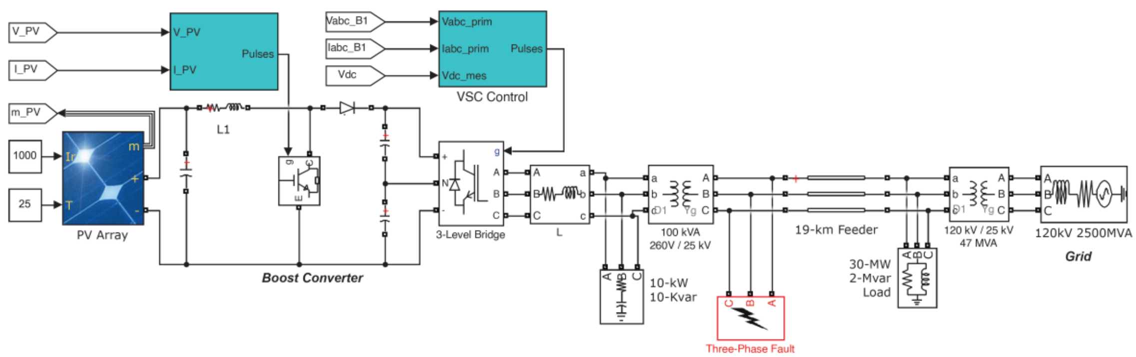
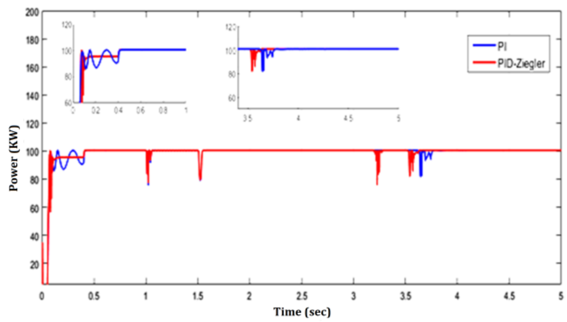
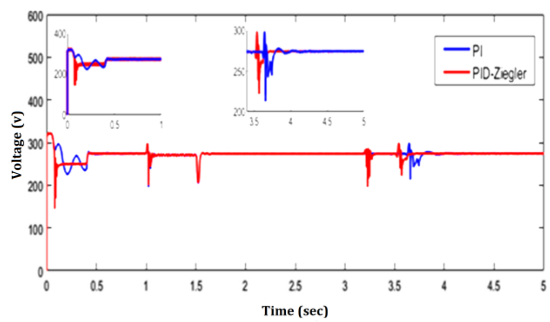


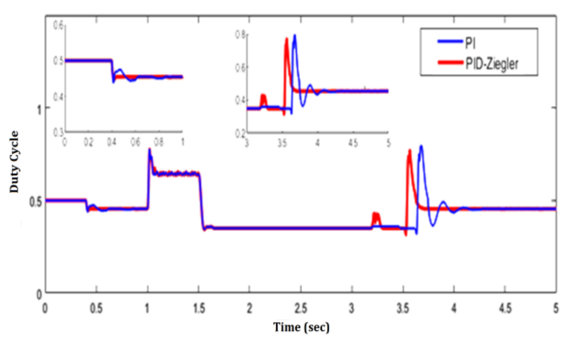
Figure 6- MATLAB–SIMULINK of the studied DC microgrid system



(a) Power versus time



(b) Voltage versus time



(c) Duty versus time

Figure 7- Effect of Variation of solar irradiance and temperature with time

Simulation results show that the variation of output power, voltage and duty cycle occurs in the grid during 3-phase to ground fault. The variation occurs through a short period where increase at start of the fault and cleared after fault clearance. So, the fault gives rise to abnormal operating conditions, usually excessive voltages and currents at certain points on the system. In the figure, control systems save the system from abnormal conditions. PID using Ziegler–Nichol is the best performance.

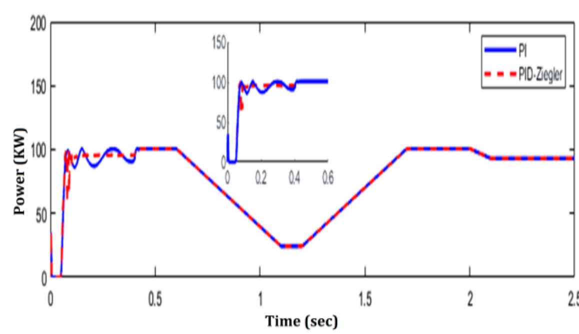
Table (2) shows a Comparison between the different controllers PI and Ziegler–Nichol based PID under effect of 3-phase to ground fault.

Table 2- Comparison between PI and PID under effect of 3-phase to ground fault.

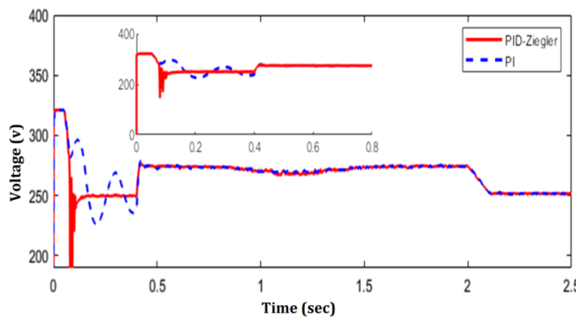
Controller	Rise time	Peak time	Settling time	Steady-state error
PI	0.19	100	0.5	0.19
PID-Ziegler Nichol	0.17	98	0.1	0.002

Case 2:

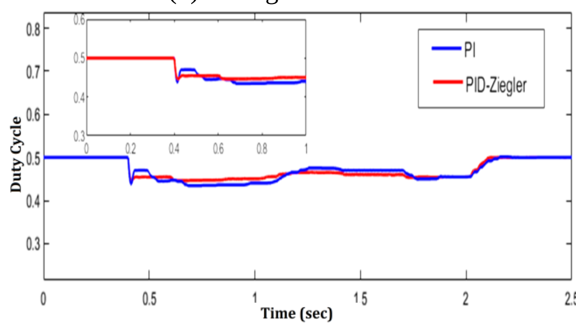
Figure (8) shows a comparison between PI and PID based Ziegler–Nichol method on the output power, the voltage and duty cycle under changes the irradiance varies from 250 to 1000 w/m^2 and temperature varies from 25 to 50 °C.



(a) Power versus time



(b) Voltage versus time



(b) Duty versus time

Figure 8- Effect variation of solar irradiance and Temperature using different controllers

Simulation results show that, the proposed Ziegler–Nichol based PID controller provides enhanced performance, where the percentage of overshoot and settling time are lower, also this method improves the transient response of the system and decrease the steady-state error.

Table (3) shows a Comparison between the different controllers of PI and PID- Ziegler Nichol under changes in the irradiance and temperature

Table 3- Comparison between PI and PID under effect under changes in the irradiance and temperature

Controller	Rise time	Peak time	Settling time	Steady-state error
PI	0.10	100	0.49	0.15
PID-Ziegler Nichol	0.08	98	0.14	0.001

5. Conclusion

This paper has presents an effective controller to design for power system based on DC microgrid. The proposed design of DC microgrid has been analyzed and simulated by using MATLAB–SIMULINK. The behavior of the overall system including the DC microgrid has been studied under variation in temperature and irradiation. Varying irradiance and temperature have been applied to study the change of power with the changing operating conditions. Also, a three- phase to ground fault has been applied on the system, which rises to abnormal operating conditions and become the system unstable. Control system have been applied as protective schemes to save the system from the abnormal conditions. The parameters of the PID controllers have been adjusted using Ziegler–Nichol method. Comparisons between PI and PID using Ziegler–Nichol have been represented investigate the performance of the system using two cases studies. Ziegler–Nichol method is efficient where it produces improved settling time and overshoot and decreases the steady-state error.

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Abbreviations

PV	Photovoltaic
DC-MG	Direct current microgrid
AC	Alternating current
DC	Direct Current
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
RES	Renewable Energy Sources
PI	Proportional-Integral
PID	Proportional-Integral Derivative
t_p	Peak Time
T_t	Rise Time
T_s	Settling Time

Parameters and Variables

I_{ph}	PV cell photocurrent
I_{pv}	Output current of PV array
I_{sc}	Short circuit current of PV modules
R_{sh}	Shunt resistance
I_{sat}	Diode saturation current
K	Boltzman constant
R_s	Series resistance
Q	Charge of an electron
V_{pv}	Output voltage of the PV array
G	Irradiance
E_g	Energy band gap
V_t	Thermal voltage of cell