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Design of a Propotional Resonant Controller with a Fractional Order PID for Improving Voltage Regulation in a Multi-Bus Microgrid System

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Abstract: Due to the shadow impact on solar PV systems, unpredictable variations in wind turbine speed, and single-phase loads, improving dynamic responsiveness and voltage control in multi-Bus Microgrid systems is a hard task. In order to improve dynamic responsiveness and voltage regulation in a multi-bus microgrid system, this study describes the design of fractional order PID (FOPID) and proportional resonant controllers (PR). The Quadratic Boost Converter (QBC) modelling analysis is used to increase the output voltage of solar PV systems. The proper switching pulses (or signals) for the QBC are created by the closed loop FOPID & PR controllers. By varying the duty cycle of the QBC, these switching pulses will affect the multi-bus microgrid system's dynamic responsiveness and voltage regulation is enhanced. In the MATLAB/Simulink environment, the comparison of dynamic behaviour and time domain load voltage characteristics at bus-3 utilising FOPID and PR controllers is examined.

Keywords: Microgrid System, Voltage Regulation, Proportional resonant controller, Simulink environment, wind turbine speed

1. Introduction

Now-a-days, the power generation is shifting from non-renewable energy sources to renewable energy sources for a different reason. It comprises decreasing the effects of global warming and the gradual decaying of energy supplies[1] (coal, gas and nuclear), addressing the increasingly growing energy demand, meeting the need for local economic and social growth, minimizing power losses. Micro grid system is currently a conceptual solution to fulfil the commitment of reliable power delivery for future delivery [2]. Classifications, operational modes, opportunities and benefits of DG units in a microgrid system was explained [3]. This interest has expressed planning, modelling, and simulation of inter connected microgrid system. The control strategy for microgrids is a key challenge for making

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microgrids a controllable unit through a converter. The converter control methods vary from AC to DC microgrid [4]. The energy generation has been reduced due to the shadow effect of solar PV panels [5]. Therefore, with a solar PV cell, a voltage boost cycle may be used to increase the output voltage [6]. This problem can be solved by using a DC-DC converter with an MPPT algorithm that injects a lower current input into the source [7], thereby increasing the performance and life time [8] of the solar PV array [9].

The conventional boost converters suffer high voltage stresses of the switch, high duty cycle and limited conversion ratio. To overcome this type of problems, a quadratic boost converter (QBC) has been used[10]. The QBC has the high voltage gain with reduced switching losses [11]. The modelling analysis, control approach and operating modes of QBC converter have been explained [12]. Multi-bus microgrids will play a key role for a successful management and control of distribution network in the future smart grids [13]. Technical issues have arisen in the multi-bus microgrid network, and the design and study of multi-bus microgrid controllers has been effectively explained in [14]. The design study and the implementation of proportional resonant (PR) controllers such as, voltage regulation of grid-connected converters, elimination of steady state errors and improvement of transient response are efficiently described [15]. The classical PID controller has only three parameters to tune, which limit the tuning strategy and little scope for tuning [16]. To overcome this problem by the introduction of additional parameters that is the order of integrator and differentiator is called FOPID controller [17]. The design analysis, tuning of FOPID controller and application such as AVR control, load frequency control of two area power system network has explained [18]. Design of 4-bus microgrid system during disturbance mode with incorporation of renewable energy sources using MATLAB Simulink. The above literature does not deal with quadratic boost converter -based PV system, enhancement of voltage regulation and dynamic response of four bus micro-grid system [19].

The main objectives of this paper were:

- Design of QBC-based solar PV system and suggests suitable controller to enhance the response of QBC.
- The enhancement of voltage regulation and dynamic response of 4- microgrid system during disturbance using FOPID, PR controllers.
- The comparison of voltage dynamic response behaviour using FOPID, PR controllers in MATLAB/Simulink.

2. bus Microgrid System

Figure 1 presents the block diagram of 6.96kV peak voltage, 50 HZ, single phase grid tied 4-bus AC micro-grid system. It consists of power sources such as AC grid supply, wind and solar energy,

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generator side converters, DC-DC Converters, Grid side converters, LC filters, Step up transformer, switches and different types of loads [20]. In this 4-bus microgrid system, the AC utility grid was connected to bus-1, the wind energy sources were connected to bus-2. The solar PV source and specific type of R, RL loads through breaker were connected to bus 3. Using this breaker, disturbance is created at bus-3 and it operates based on the external selection of switching time option. A Simulink logical signal is used to control this breaker operation.

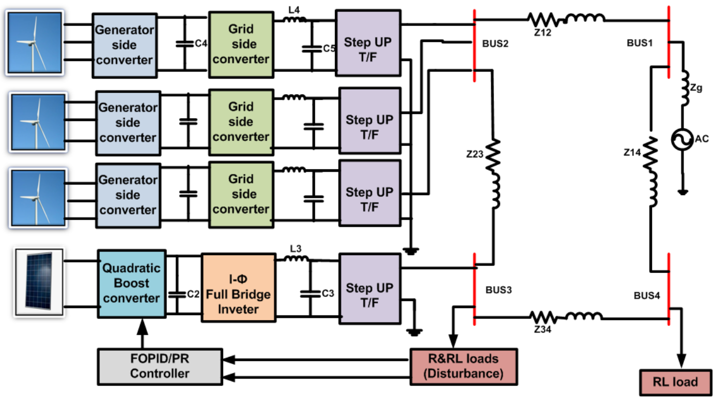

Figure 1. Block diagram of proposed 4-bus Microgrid System

The common DC link voltage was connected to the Quadratic boost converter (QBC), which boost the DC power from the solar PV array. The solar PV array system is designed with peak capacity of 7.4kW. The Wind turbine generation is used to maintain voltage and frequency equal to the grid system and also to synchronize output of the inverter connected to the grid.

Table-1 Line and Load parameters in microgrid system

Line	**Line Impedance**
1-2	0.005Ω, 0.023mH
1-4	0.1 Ω, 0.34mH
2-3	0.15 Ω, 0.38mH
3-4	0.2 Ω, 0.45mH
Load	Load Impedance
At bus 3	100Ω, 75mH75 Ω (R load with disturbance)

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At bus 4	100Ω, 75mH

Figure 2 shows the block diagram of Solar PV array connected to Quadratic boost converter (QBC). It consists of single MOSFET switch, two capacitors (C1, C2), two inductors (L1, L2) and three diodes (D1, D2, D3).

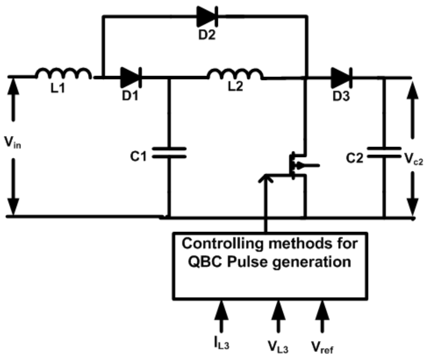

Figure 2. Quadratic boost converter

3. Design of Controllers

It is important to minimize the impact of the control voltage on the load bus and to ensure the stable operation of the micro grid system. Closed loop microgrid system always shows better dynamic performance than open loop microgrid system. All of the control methods below are used to generate the appropriate QBC switching pulses (or signals) when considering bus-3 load voltage and current as a reference.

3.1 Design of Fractional Order PID Controller

In this Fractional order PID controller, three design variables, and two additional variables, such as , (order of integral and differentiation variables which are positive real numbers and not necessary integers). The block diagram of FOPID controller is shown in Figure 3. This FOPID controller provides good performance by tuning five variables instead of three variables in PID controller.

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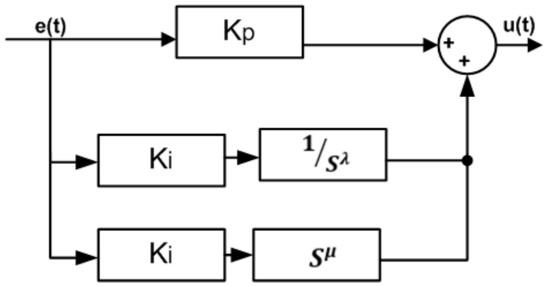

Figure 3. Block diagram of FOPID controller

The block diagram FOPID controller based closed loop system is shown in Figure 4. The reference voltage () in the outer control loop is the required RMS voltage, to have good dynamic response and improve voltage regulation by adjusting the actual RMS voltage by control of quadratic boost converter switching pulse. The load voltage and current at bus-3 can be controlled by using two FOPID controllers.

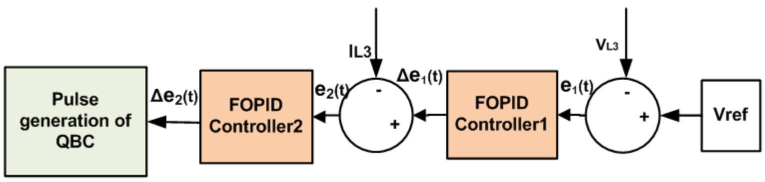

Figure 4. FOPID controller based closed loop control system

4. Simulation Results and Discussion

The bus-3 load voltage in the 4-bus microgrid network differed due to the addition of load or the removal of loads from the microgrid system. The Solar PV array system with quadratic boost converter is used to regulate the voltage and improve the regulation of the voltage. Simulation parameters of solar energy system, quadratic boost converter values, DC capacitance values, LC filters, FOPID controller parameters and PR controller parameter values are given in Table 2. Figure 7 displays the Simulink diagram of the open loop and the closed loop 4-bus microgrid network with FOPID and PR controllers.

In the proposed system, the difference of reference voltage (Vref=4000V) and rms load voltage at bus-3 is connected as inputs of first FOPID controller. Based on input error, the FOPID parameters have changed. The difference between the load current on bus-3 and the output of the first FOPID controller was connected to the input of the second FOPID controller. The same method can be extended to the

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closed loop PR controller based on a closed - loop system. Two FOPID and PR loop controllers are used in voltage and current loops. The current loop pulse generator compares the output of the FOPID and PR controllers to the triangular waveforms. The pulse generator output signal was connected to the Quadratic boost converter input gate switching pulse.

Figure 8 represents the Simulink diagram of solar PV array is connected by a quadratic boost converter. The output voltage solar PV array is connected to the input of the QBC and its output is connected to the input of the inverter. After the LC filter is used to filter the harmonics and finally the step-up transformer is used to raise the voltage level base of the bus-3 voltage.

Table-2 Simulink parameters of the proposed configuration

Parameter	Value	Parameter	value
I_{pv}=I_{ref}	4.85A	C5	550µF
$I_{rradiance}$	1000 w/m^2	kp1	6.1
SC $_{current}$	5.45 A	ki1	5.7
V_{max}	1500V	kd1	3.84
I_{max}	4.95A	1	1.91
V_{oc}	1500V	1	1.8
V_{pv}	1523.7V	kp2	0.3
P_{pv}	7390W	ki2	0.53
L_1	1mH	kd2	0.3
L_2	10mH	2	1.8
L3	1000mH	2	0.133
C_1	10mF	KP1, KP2	0.5, 0.5
C_2	10mF	KR1, KR2	0.06, 0.1
C_3	250µF	W01, W01	0.424, 0.227
L_4		110mH	
C_4		300µF	

The output voltage of both solar PV array and quadratic boost converter are shown in Figure 9 and its values are 1524V, 3250V. The output of QBC was connected input of inverter. The conversion AC value connected to bus-3 through LC filter and step-up transformer. The voltage gain of QBC is more compared to conventional boost converter and this output voltage of QBC is equal to square that of boost converter. The Simulink results of voltage, current, active power, reactive power of load at bus-3 with open loop system, FOPID and PR controllers are given in Figure 10(a)-(b). The steady state rms value of load voltage at bus-3 with open loop disturbance, FOPID and PR controllers are 2939V, 3908V, 4082V. The steady state rms value of load current at bus-3 with open loop system, FOPID and PR controllers are like 22.92A, 31.8A, 35.0A. The steady state rms value of real power at bus-3 with open

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loop disturbance, FOPID and PR controllers are like 59.10kW, 121.1kW, 140.31kW. The steady state reactive power at bus-3 with open loop, FOPID and PR controllers are like 13.92kvar, 28.47kvar, 33.93kvar. From the figures, due to control of quadratic boost converter switching pulse, the required load voltage and load current at bus-3 in multi-bus microgrid system has been varied and get the good dynamic performance. Based on load voltage and load current, the active power and reactive power also changed. Figure 10(b) represents the instantaneous sinusoidal load voltage and load current wave forms of multi bus microgrid system at bus 3.

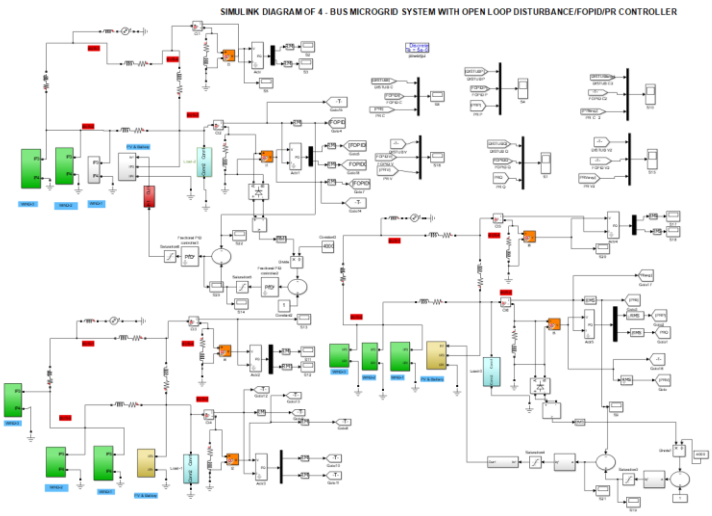

Figure 7. Simulink diagram of Multi-bus Microgrid system with open loop, FOPID, PR controller

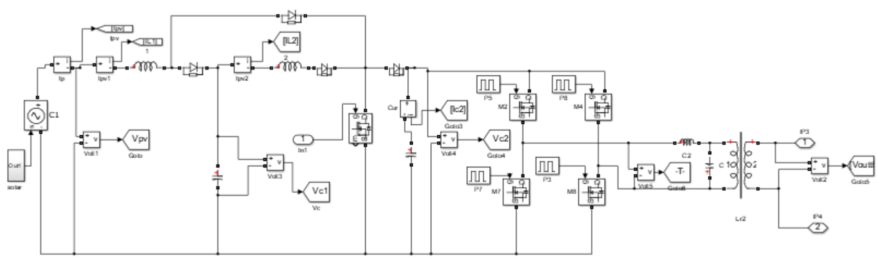

Figure 8. Simulink diagram of Solar PV array connected QBC

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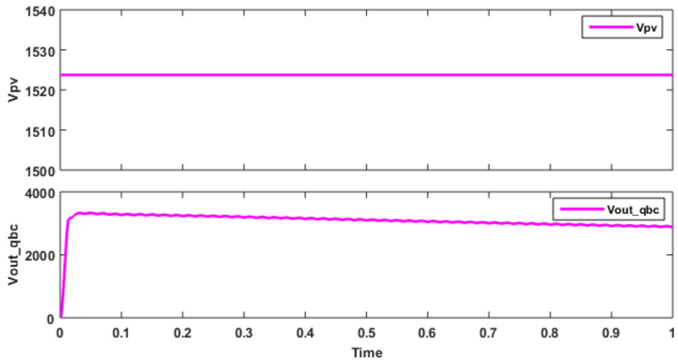
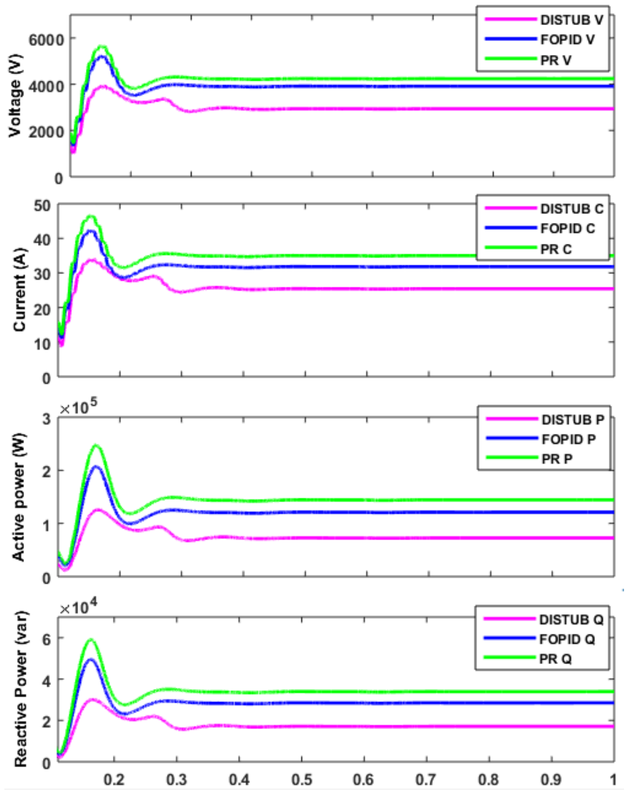


Figure 9. Output voltage of both solar PV array& Quadratic boost converter



(a)

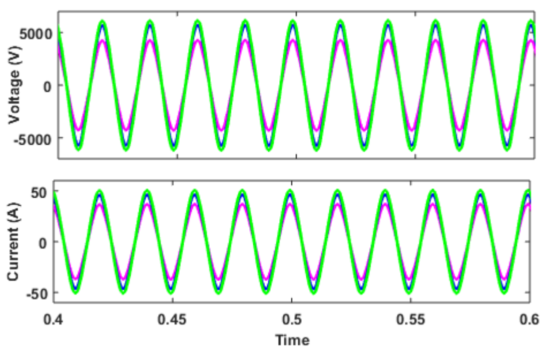


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Figure 10. Simulink results of (a)V_{l3}_rms, I_{l3}_rms, Pl3, Q_{l3}, (b) V_{l3}, and I_{l3} under open loop, FOPID and PR Controller based multi bus microgrid system

Table.3: Performance analysis of 4-bus microgrid system

Time Domain Parameters of load voltage at bus-3				
Controller type	Tr Rise time	Tp Peak time	Ts Settling time	Ess Steady state Error (%)
Open loop system	0.124	0.158	0.691	26.52
FOPID	0.122	0.152	0.674	2.30
PR	0.120	0.150	0.664	2.05

Table 3 shows the performance analysis of 4-bus micro grid system using FOPID and PR controllers. Form the table it is observed that the rise time, peak time, setting time and steady state error of the open loop microgrid system is more than the closed loop microgrid system. It is shown that the rise time is declined from 0.122s to 0.120s, the peak time is declined from 0.152s to 0.150s, the settling time is declined from 0.674s to 0.664, the

steady state error is declined from 2.30% to 2.05% when compared to PR controller with FOPID controller. It is also analysed from the Figure 10(a) and Table- 3 that voltage regulation and dynamic response improvement in multi-bus microgrid can be achieved using PR controller.

5 Conclusion

MATLAB Simulink is used to model and simulate the multi-bus microgrid system with open loop, closed loop FOPID, PR controller, and solar PV array using quadratic boost converter. Analysis is done on the simulation outcomes for the multi-bus microgrid system with FOPID and PR controller. The findings indicate that the voltage gain of the QBC is greater than that of the standard boost converter. The open loop system has a poor dynamic responsiveness and a higher steady state error or voltage regulation than the closed loop FOPID, PR controller. Since rising time, peak time, and settling time are decreased with a closed loop PR controlled multi bus microgrid system compared to a closed loop FOPID controlled multi bus microgrid system, the dynamic reaction is quicker. an increase in voltage The PR controller improves voltage regulation more than the FOPID controller.

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