Comparative Analysis of LQR and Hysteresis Control for Voltage and Power Regulation in a Four-Bus Microgrid

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ABSTARCT

The work incorporates the control strategies in closed loop control of quadratic boost converter based four bus micro grid using –HC (hysteresis controller) and LQR (linear quadratic regulator) controllers. The suggested LQR controls the voltage and current at load buses by using Hybrid Power Flow Controlled system. This work deals with the comparison of closed loop four bus system using HC/LQR controller. Simulation is done for 4 bus system & the outcomes are compared in terms of settling time and steady state error. The outcomes represents that the superior performance of LQR controlled 4 bus system compared to HC controlled 4 bus systems.

Keywords: Four bus, microgrid, hysteresis controller, linear quadratic regulator and quadratic boost converter.

1. INTRODUCTION

A fractal approach with a triangularization procedure was proposed and dissected to take out the external hysteresis band and query table for area change location. The curiosity proposed in this article was the mix of the fractal way to deal with CESP-based hysteresis regulator, which diminishes the intricacy of the execution of CESP-based hysteresis regulator for any broad staggered front-end converter [1].

A current-blunder space-vector-based hysteresis current regulator for an overall n - level voltage-source inverter (VSI)- took care of three-stage enlistment engine (IM) drive was proposed here, with control of the exchanging recurrence variety for the full direct balance range. Proper aspect and direction of this explanatory limit guaranteed an exchanging recurrence range like that of a steady exchanging recurrence voltage-controlled space vector beat width balance (PWM) (SVPWM)- based IM drive [2].

A consistent exchanging recurrence hysteresis regulator in light of current mistake space vector (CESV) for two-level voltage source inverter took care of enlistment engine (IM) drive is proposed in this paper. Here the stator voltages along the α-and β-tomahawks are assessed utilizing current blunder data and consistent state model of IM [3].

An original heartbeat width balance (PWM) procedure was proposed for a current space vector hysteresis current regulator (SVHCC) conspire. A three-level impartial point-cinched (NPC) inverter was utilized for double motivation behind shunt dynamic power separating and sun based photovoltaic (PV) power incorporation to a dissemination framework [4].

The ongoing mistake space vector-based hysteresis regulator with almost consistent exchanging recurrence for voltage source inverter (VSI) took care of extremely durable magnet simultaneous machines drive was proposed. With the proposed regulator, the Quick Fourier transformer profile of the result voltage created by the VSI is like that of a space vector tweaked VSI, by keeping up with almost steady exchanging recurrence [5].

An original various information different result (MIMO) state-space model, free of the mover's speed, having stator transition and pushed force as states, was figureured out for the straight long-lasting magnet coordinated engine (PMSM). An ideal direct state criticism control plot was then planned utilizing the ideal straight quadratic controller strategy [6].

A strategy for registering the answer for the boundless skyline nonstop time obliged straight quadratic controller was proposed. The strategy depended on two primary fixings: a multi matrix strategy for setting a limited number of time stretches, and a piece-insightful direct definition of the contribution inside the spans [7].

A stage toward demystifying the exhibition and productivity of such strategies by zeroing in on the standard limitless skyline direct quadratic controller issue for consistent time frameworks with obscure state-space boundaries was taken. We additionally gave hypothetical limits on the assembly rate and test intricacy of the arbitrary pursuit technique with two-point angle gauges [8].

To limit the changes and give a smooth progress, this paper presents an ideal control structure in view of direct quadratic controller. Optimality in view of enhancing arrangement, smooth progress, simplicity of execution because of its basic state criticism structure and similarity with recognizable outpouring circles are the principal benefits of the proposed approach [9].

This work introduced a better straight quadratic-controller control calculation. A rate control regulation with no static mistake was proposed in view of the customary straight quadratic-controller to take out the static blunder of the state vector and accomplish a superior control impact. Furthermore, a shut circle state spectator was utilized to gauge the framework's state vector, and a dynamic corrector was intended to decrease rolling and heading point deviation brought about via ocean wave obstruction [10].

An expense capability was built for the irregular limited set-based swarm direction issue motorized by Gaussian combinations. This cost capability utilized a computerized issue subordinate scaling and presented an activator capability for quadratic assembly of distant Gaussians. Then a lengthy direct quadratic controller (LQR) was characterized for the multitude issue as an improvement to the iterative LQR (ILQR) [11].

This work proposed a stochastic control system, to be specific the unsynchronized Habit-forming Increment Multiplicative Decline (AIMD) calculation, to deal with the power stream of interconnected microgrids (MGs). The proposed control pointed toward accomplishing a tradeoff between the singular utility capability of every MG while guaranteeing the solidness of the grid[12].

This work proposed a superior MADC technique for the dc microgrid. The proposed control technique limits the unfavorable impacts of the previously mentioned voltage drops on the transport voltage guideline and the power dividing among the DERs in the dc microgrid [13].

This work proposed a period space based security conspire for outspread and circle microgrid frameworks with inverter-based assets (IBRs, for example, sun oriented photovoltaic (PV) frameworks and type-4 breeze turbines. The assurance plot was intended to work during both network interconnected and framework segregated modes [14].

This article proposed a conveyed optional level control technique for dc microgrids, which accomplishes exact and relative power sharing and dc-transport voltage deviation rebuilding in view of voltage moving. Rather than comparative methodologies, just a single variable for every converter was sent in the low-transmission capacity correspondence connect and with a basic integrator as the optional level regulator the two targets are accomplished all the while [15].
The inertial control calculation utilizing a synchronverter is empowered for variable-speed wind turbines. Moreover, the sort 4 long-lasting magnet coordinated generator wind turbine generator utilizing synchronverter inertial control is displayed and the thorough investigation and correlation are directed between recurrence based inertial control and synchronverter inertial controls [16].
An ideal disseminated voltage control for lattice shaping (GFM) inverters in islanded AC microgrids was proposed [17]. An improvement issue was figureured out where the conveyed generator (DG) yield voltage was considered as the control variable with specialized limitations on voltage and responsive power yield limit and a goal capability that makes a compromise between voltage guideline and receptive power sharing.
This work[18] proposed an ideal and single assurance plot appropriate for all working methods of microgrid alongside each sort of stage deficiencies in the framework, i.e., three-stage even (3-φ), line-to-line, and twofold line-to-ground issues. The ideal setting of the directional overcurrent transfers was gotten utilizing a meta heuristic-based enhancement calculation.
This work proposed a versatility-based strategy that utilizes microgrids to reestablish basic burdens on dispersion feeders after a significant debacle. Because of restricted limit of disseminated generators (DGs) inside microgrids, dynamic execution of the DGs during the reclamation cycle becomes fundamental [19].
This work proposed an internet based versatile Koopman administrator ideal control (AKOOC) strategy for MG auxiliary voltage and recurrence control. Dissimilar to commonplace information driven strategies that were information hungry and need ensured steadiness, the proposed AKOOC requires no warm-up preparing yet with ensured limited input-limited yield (BIBO) strength and even asymptotical solidness under a few gentle circumstances [20].

2. RESEARCH GAP

The above literature does not deal with the Power quality improvement of four Bus System using closed loop linear quadratic Controller. Hence the proposed work compares the responses of HC and LQR Controllers and suggests LQR for MGS under closed loop conditions.

3. SYSTEM DESCRIPTION

Block diagram of a micro-grid system with LQR/HC controller is shown in Figure 1. Output of PV is stepped up using QBC. The output of QBC is in viewed and it is applied to the load. Load voltage is sensed and it is compared with reference voltage. The error is applied to LQR/HC. The current reference is obtained and it is compared with actual current and error is applied to LQR/HC. The output of LQR/Controls PW of QBC.The line diagram of the system is shown in figure 2.

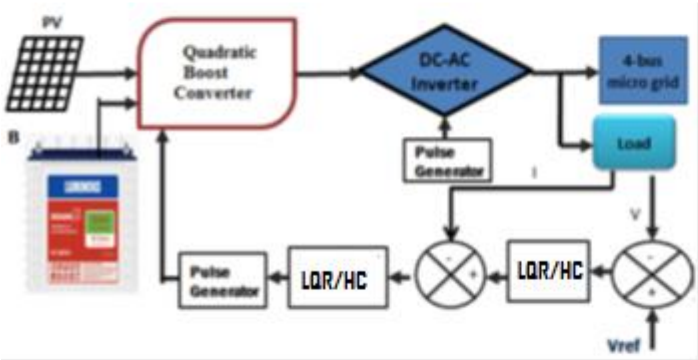

Figure 1. Block diagram of HPFC with LQR-LQR/HC-HC controller

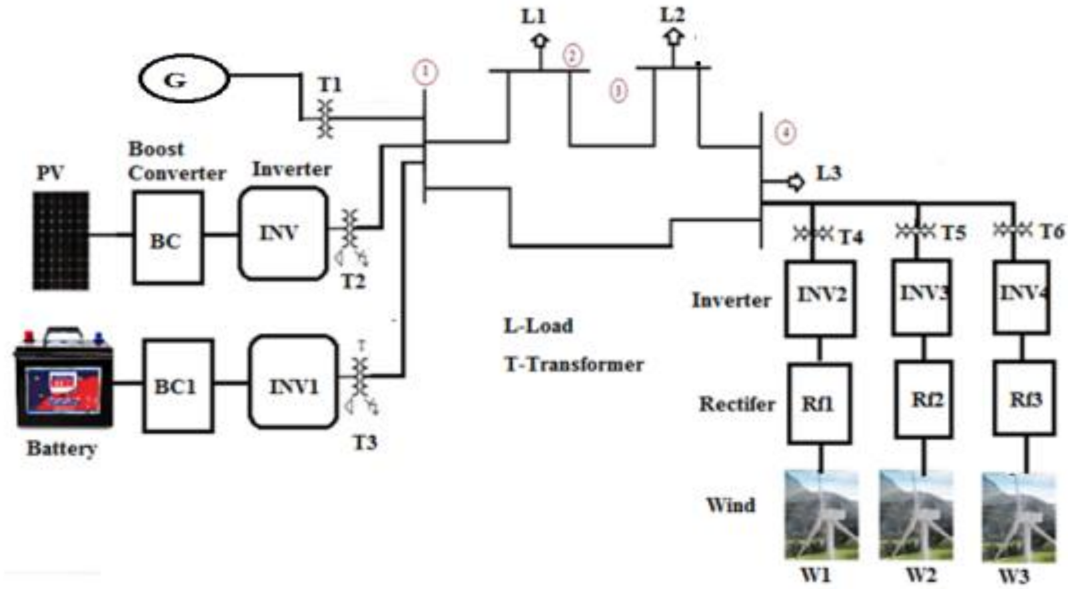

Figure 2. Line diagram of 4-bus system

4. SIMULATION RESULTS AND DISCUSSION

A) Closed loop –Hysteresis controlled 4-bus micro grid system

Circuit diagram of closed loop HC-HC controlled four bus micro grid system is appeared in Figure 3. Voltage at bus-3 in closed loop HC-HC controlled four bus micro grid system is shown in Figure 4 and its value is $0.8*10^4$ Volts. RMS Voltage at bus-3 in four bus system is shown in Figure 5 and its value is 4800 Volts. Current at bus-3 with HC is shown in Figure 6 and its value is 60A. RMS Current at bus-3 with HC is shown in Figure7 and its value is 42A. Real power at bus-3 in 4-bus system is appeared in Figure 8 and its value is $1.8*10^5$ Watts. Reactive power at bus-3 in 4-bus system is appeared in Figure 9 and its value is $1.2*10^4$ VAR.

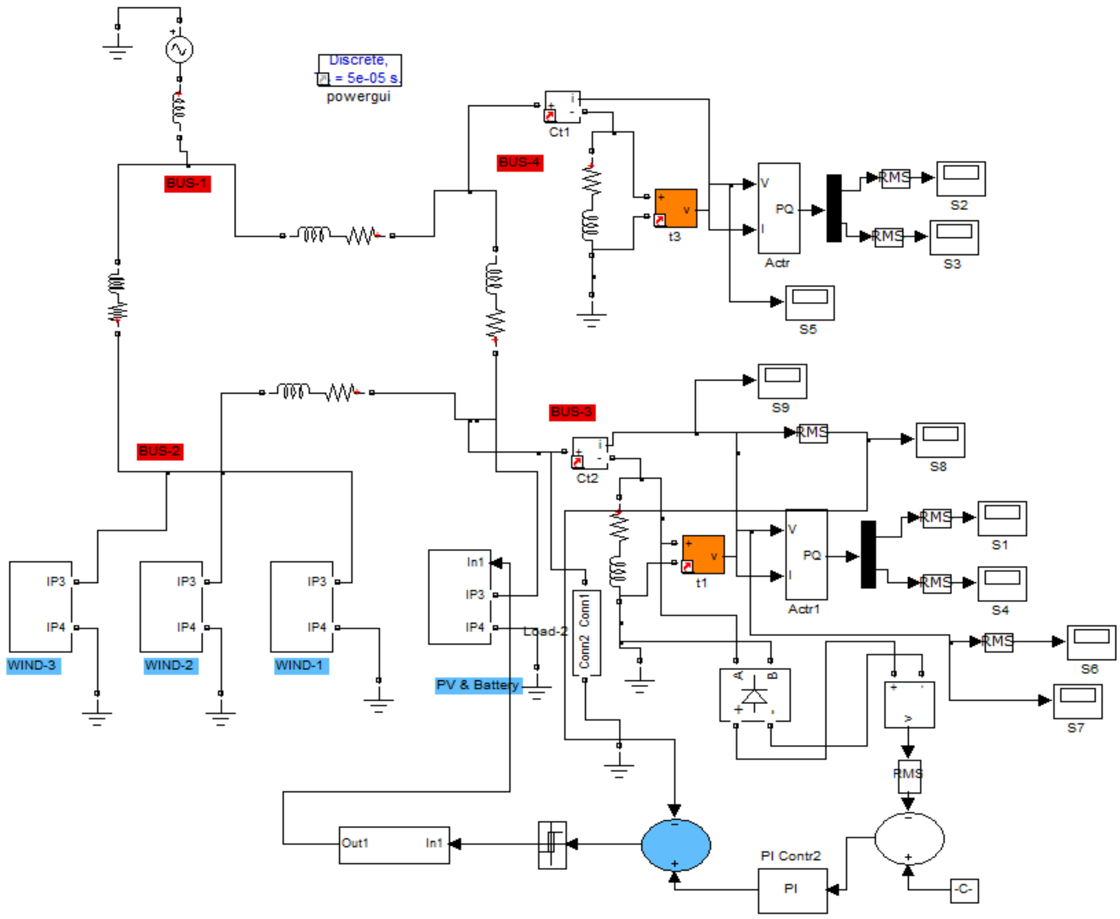

Figure3.Circuit diagram of 4-bus micro grid with closed loop HC controller

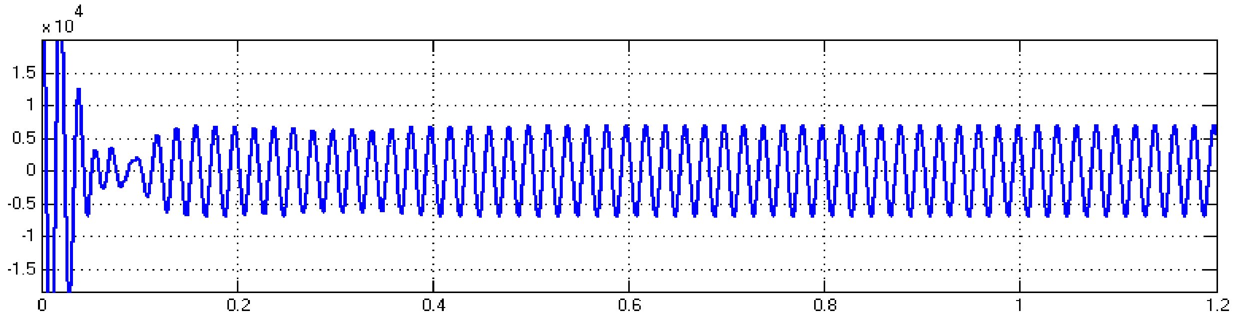

Figure4.Voltage at bus-3 with HC

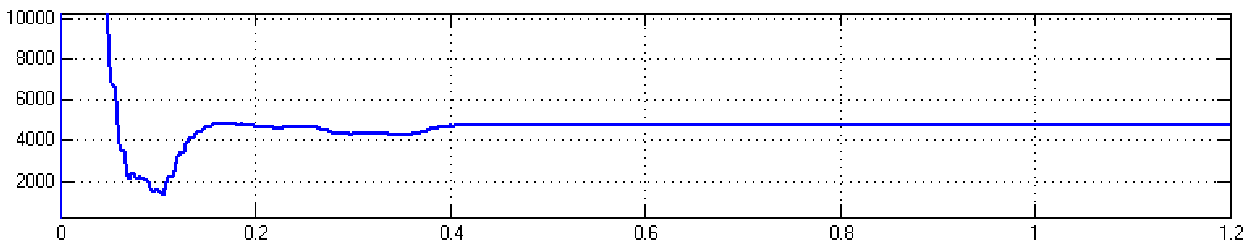

Figure5.RMS voltage at bus-3 with HC

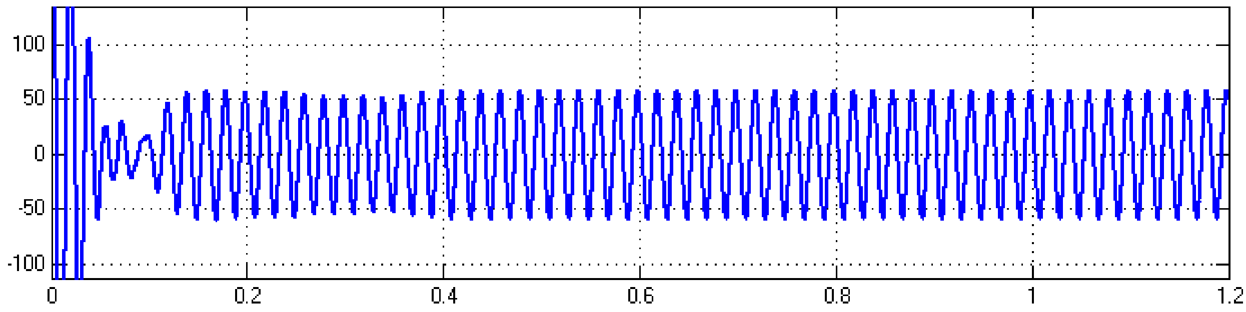

Figure6.Current at bus-3 with HC

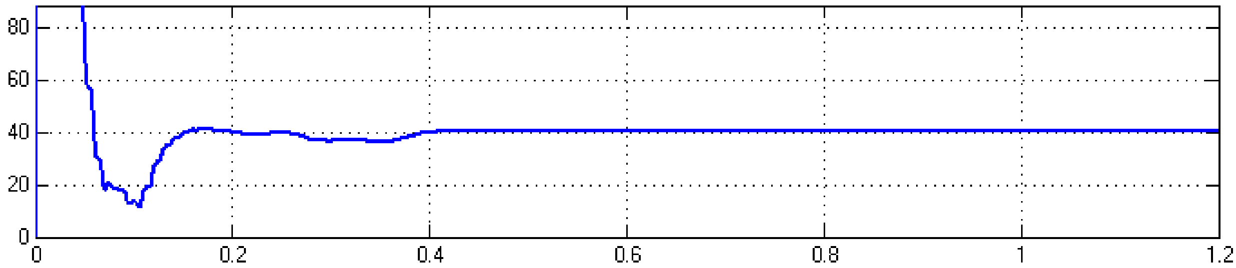

Figure7.RMS Current at bus-3 with HC

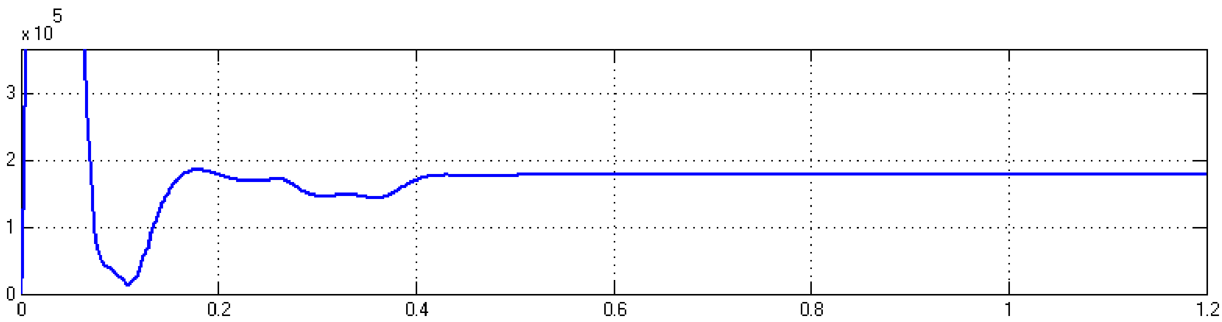

Figure8.Real power at bus-3 with HC

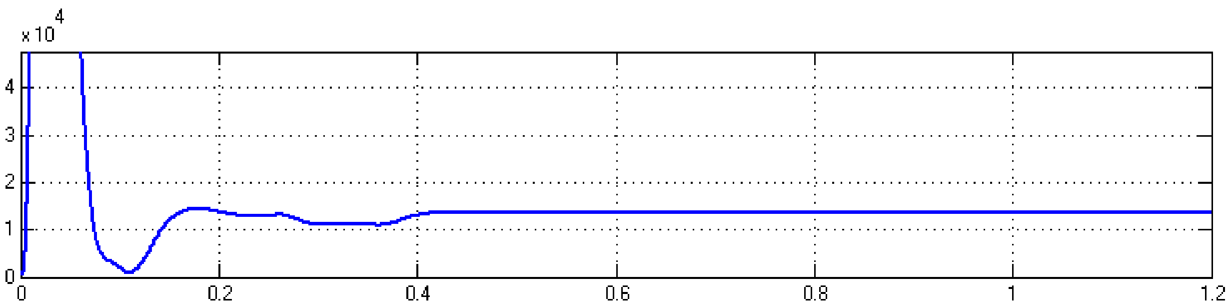

Figure9.Reactive power at bus-3 with HC

B) Closed loop –LQR controlled 4-bus micro grid system

Circuit diagram of closed loop LQR-LQR controlled four bus micro grid system is appeared in Figure 10. Voltage at bus-3 in closed loop LQR-LQR controlled four bus micro grid system is shown in Figure 11 and its value is $0.8*10^4$ Volts. RMS Voltage at bus-3 in four bus system is shown in Figure 12 and its value is 4800 Volts. Current at bus-3 with LQR is shown in Figure 13 and its value is 60A. RMS

Current at bus-3 with LQR is shown in Figure14 and its value is 42A. Real power at bus-3 in 4-bus system is appeared in Figure 15 and its value is $1.8*10^5$ Watts. Reactive power at bus-3 in 4-bus system is appeared in Figure 16 and its value is $1.2*10^4$ VAR.

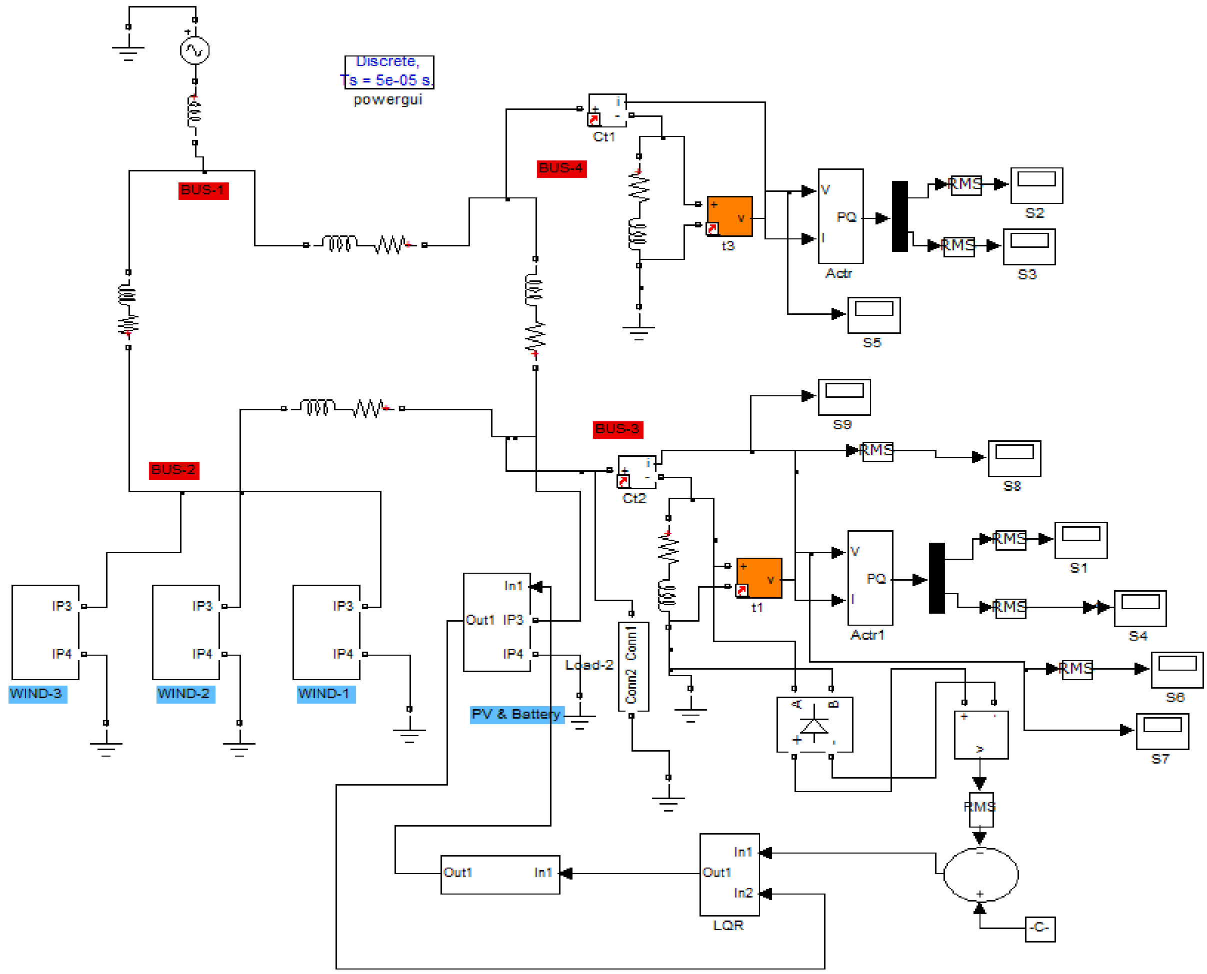

Figure.10 Circuit diagram of 4-bus micro grid with closed loop LQR controller

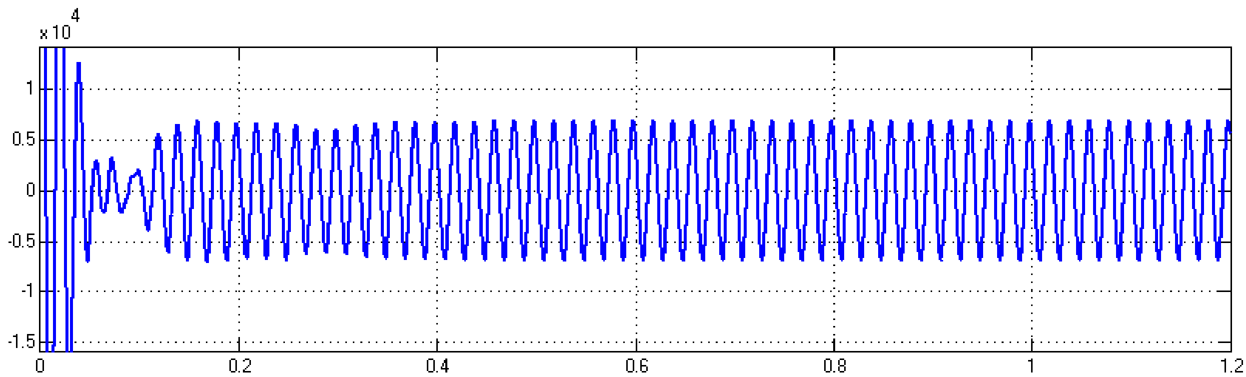

Figure11.Voltage at bus-3 with LQR

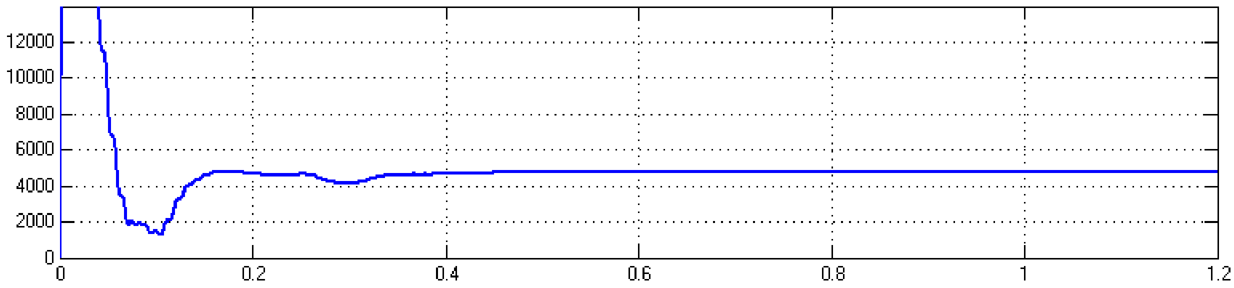

Figure12. RMS voltage at bus-3 with LQR

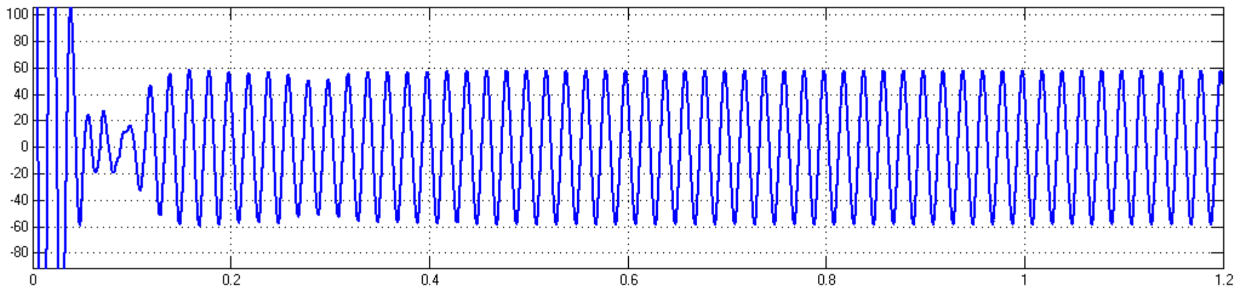

Figure.13. Current at bus-3 with LQR

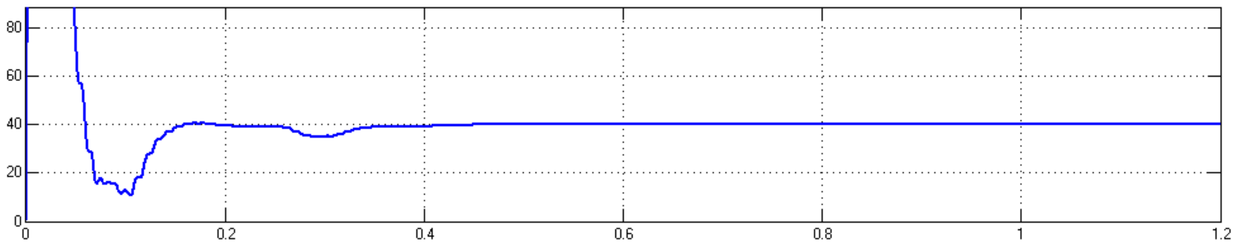

Figure.14.RMS Current at bus-3 with LQR

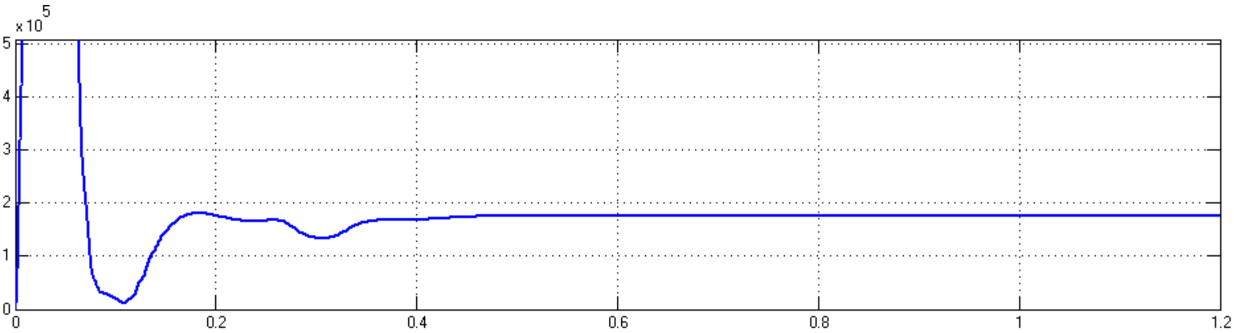

Figure.15 Real power at bus-3 with LQR

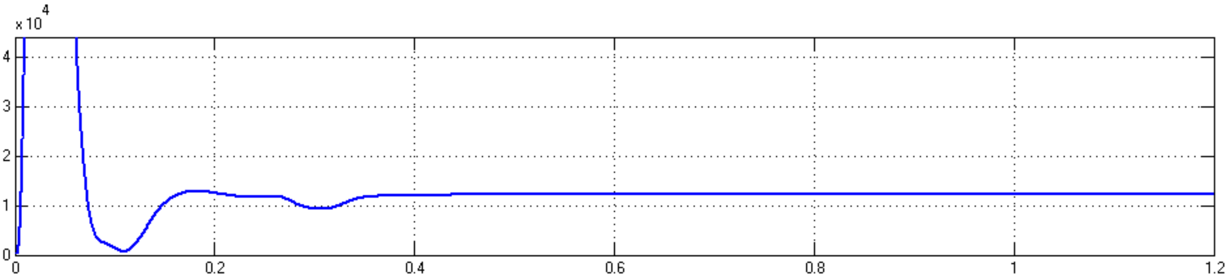

Figure.16. Reactive power at bus-3 with LQR

C) Comparison results of Time domain parameters using LQR-LQR/HC-HC controlled 4-bus micro grid system (voltage) at bus-3

Comparison of time domain parameters for voltage at bus - 3 using LQR-LQR and HC-HC controllers are given in table-1. By using LQR controller, rise-time is reduced from 0.26Sec to 0.25Sec; the peak-time is reduced from 0.35Sec to 0.30Sec; the settling-time is reduced from 0.40Sec to 0.35Sec; the steady-state-error is reduced from 1.1 Volts to 0.75 Volts. Bar-Chart comparison of four bus micro grid system with LQR-LQR and HC-HC are shown in Figure 17.

Table-1 Comparison of Time Domain Parameters (voltage) at bus-3

Controller	Tr	Ts	Tp	Ess
HC	0.26	0.40	0.35	1.10
LQR	0.25	0.35	0.30	0.75

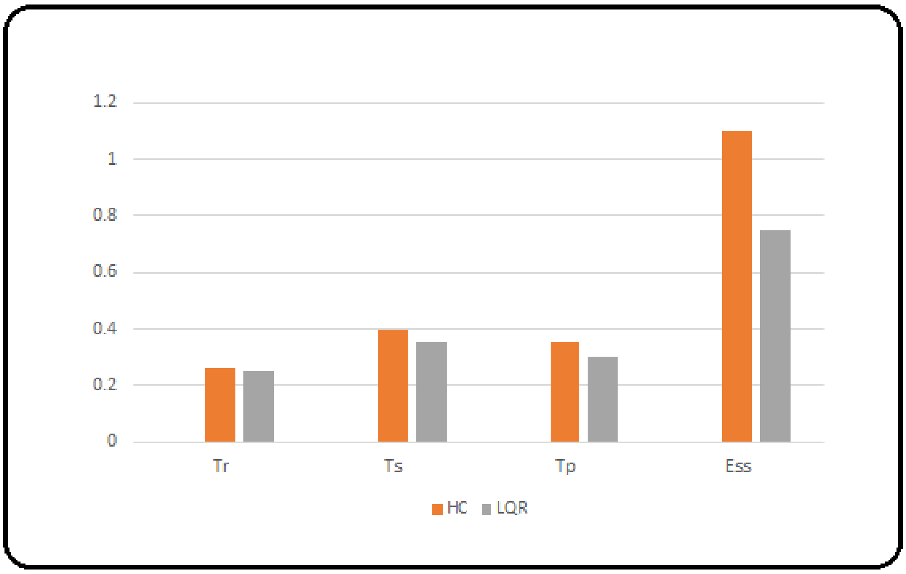

Figure17.Bar-Chart comparison of four bus micro grid system with LQR-LQR and HC-HC

D) Comparison results of Time domain parameters using LQR-LQR/HC-HC controlled 4-bus micro grid system (current) at bus-3

Comparison of time domain parameters for current at bus - 3 using LQR-LQR and HC-HC controllers are given in table-2. By using LQR controller, rise-time is reduced from 0.26Sec to 0.25Sec; the peak-time is reduced from 0.35Sec to 0.31Sec; the settling-time is reduced from 0.39Sec to 0.34Sec; the steady-state-error is reduced from 0.41 Amp to 0.32 Amp. Bar-Chart comparison of four bus micro grid system with LQR-LQR and HC-HC are shown in Figure 18.

Table-2 Comparison of Time Domain Parameters for current at bus-3

Controller	Tr	Ts	Tp	Ess
HC	0.26	0.39	0.35	0.41
LQR	0.25	0.34	0.31	0.32

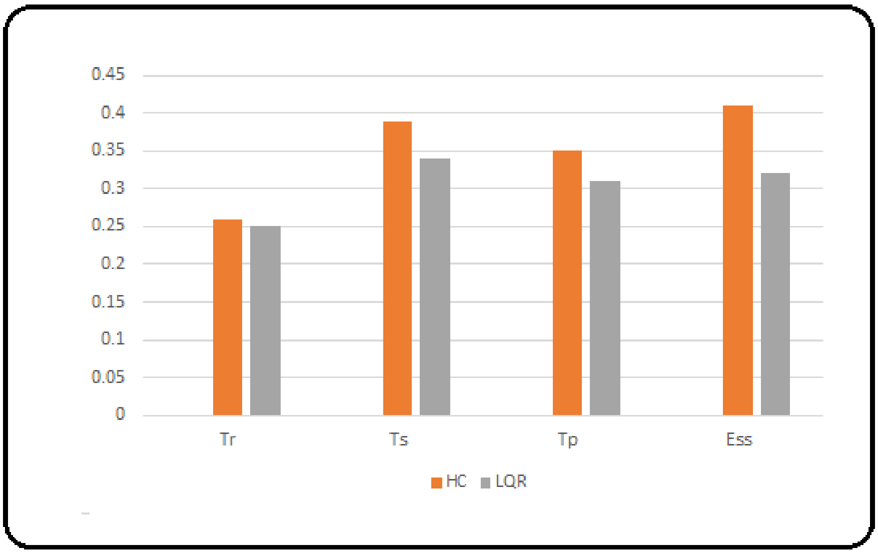

Figure18. Bar-Chart comparison of four bus micro grid system with LQR-LQR and HC-HC

5. CONCLUSION

Comparison of two loop 4 bus microgrid HPFC system using LQR-LQR and HC-HC controller are simulated. Simulation is done and the outcomes are compared in terms of settling time and steady state error. By using LQR controller, rise-time is reduced from 0.26Sec to 0.25Sec; the peak-time is reduced from 0.35Sec to 0.31Sec; the settling-time is reduced from 0.39Sec to 0.34Sec; the steady-state-error is reduced from 0.41 Amp to 0.32 Amp. Hence, the two loop-LQR-LQR controlled- 4-bus micro grid HPFC system is superior to two-loop-HC-HC controlled- 4-bus micro grid HPFC system. The advantages of LQR controlled 4-bus micro grid HPFC system are improved-time domain-response and reduced steady-state-speed-error at bus-3.

The present work deals with the simulation of two loop-LQR-LQR controlled- 4-bus micro grid HPFC system. Two loop- FLC-FLC controlled- 4-bus micro grid HPFC system can be done in future.

REFERENCES

1. M. T. Shah Siddharth Singh K. Chauhan P. N. Tekwani Fractal Approach Based Simplified-and-Generalized-Sector-Detection-in-Current-Error-Space-Phasor-Based-Hysteresis Controller-Applied-to-Multilevel-Front-End-Converters-IEEE Transactions on Power Electronics Year 2020 Volume35, Issu10 Journal Article Publish-IEEE
2. Anubrata Dey;P. -P. Rajeevan;Rijil-Ramchand;K.-Mathew;K.-Gopakumar – A-Space-Vector-Based-Hysteresis-Current-Controller for a-General n-Level-Inverter-Fed-Drive-With Nearly-Constant-

Switching-Frequency-Control-IEEE-Transactions-on-Industrial-Electronics
Year2013 | Volum60, Issu5 | Journal-Article | Publish-IEEE
3. JosephPeter;-Mohammed Shafi-K.P.;R. -Lakshmi;Rijil -Ramchand -Nearly-Constant Switching Space-Vector Based-Hysteresis-Controller for-VSI--Fed IM Drive-IEEE-Transactions on-Industry-Applications -Year2018 | Volum-54, Issu-4 | -Journal-Article | -Publish-IEEE
4. Ravi-Varma Chavali;-Anubrata Dey;-Biswarup Das -A-Hysteresis-Current-Controller-PWM Scheme-Applied to-Three-Level-NPC-Inverter for-Distributed-Generation-Interface-IEEE-Transactions-on-Power-Electronics-Year2022 | Volum37, -Issu 2 | -Jour-Article | Publish-IEEE
5. Sandeepjayaprakasan;S.-Ashok;Rijil Ramchand –Current-Error-Space-Vector-Based Hysteresis-Controller for VSIFedPMSMDrive IEEE-Transactions on-Power-Electronics -Year: 2020 | -Volum-35, -Issu10 | -Journal-Article | -PublisheIEEE
6. Muhammad AliMasoodCheema;-John Edward Fletcher;-Dan Xiao;Muhammad Faz Rahman -A-Linear-Quadratic-Regulator-Based-Optimal-Direct-Thrust-Force-Control of-Linear Permanent-Magnet-Synchronous-Motor-IEEE-Transactions on-Industrial-Electronics-Year: 2016 | Volum-63, -Issu 5 | Journ-Article | -PublisIEEE
7. GabrielePannocchia;-James B.-Rawlings;David-Q. Mayne;-Wolfgang-Marquardt On Computing--Solutions to the-Continuous-Time-Constrained-Linear-Quadratic-Regulator-IEEE Transactions-on-Automatic-Control-Year2010 | -Volu55, Issu9 | -JourArticle |- Publisher: IEEE
8. HesameddinMohammadi;-Armin Zare;-Mahdi Soltanolkotabi;-Mihailo R. Jovanović Convergence-and-Sample-Complexity of-Gradient-Methods for the-Model-Free Linear–Quadratic-Regulator-Problem-IEEE-Transactions-on-Automatic-Control-Year2022 | -Vol: 67, Iss5 | Jour-Article | Publi IEEE
9. Mohyedin-Ganjian-Aboukheili;-Majid-Shahabi;Qobad-Shafiee;Josep-M. Guerrero Linear -Quadratic-Regulator-Based-Smooth-Transition-Between-Microgrid-Operation-Modes-IEEE -Transactions-on SmartGrid-Year: 2021 |- Volu12, Issu6 | -Journ-Article | -Publi-IEEE
10. YuhanZhao;-Zhanshuo Zhang;-Jiawei Wang;-HongboWang -Fin-Rudder-Joint-Control Based-on-Improved-Linear-Quadratic-Regulator-Algorithm-IEEE-Access-Year2022 | -Vol: 10 | Jour-Article | -Publis-IEEE
11. RyanW.-Thomas;Jordan-D. -Larson-Receding-Horizon-Extended-Linear-Quadratic Regulator-for-RFS-Based-Swarms-With-Target-Planning and-Automatic-Cost-Function-Scaling, IEEE-Transactions on-Control-of-Network -Systems-Year2021 | -Volum8, Issu2 |- JourArticle | -Publis-IEEE
12. PietroFerraro-;EmanueleCrisostomi;-RobertShorten;-FedericoMilano -Stochastic -Frequency-Control -of Grid-Connected-Microgrids-IEEE-Transactions-on–Power-Systems Year2018 | Volu33-Iss5 | -Journ-Artic-| -Publi-IEEE
13. JafarMohammadi;-FirouzBadrkhani Ajaei-Improved-Mode-Adaptive-Droop-Control Strategy-for the-DC-Microgrid-IEEE-Access-Year:2019 | Vol7 | JourArticle | Publi-IEEE
14. Husam S.-Samkari;-Brian-K.-Johnson-Time-Domain-Protection-Scheme for-Microgrids With-Aggregated-Inverter-Based-Distributed-Energy-Resources-IEEE-AccessYear: 2023 | Volu-11 | -Jour-Article | -Publi-IEEE
15. WanerWodson-A. G. Silva;-Thiago R.-Oliveira;Pedro F.-Donoso-Garcia-An-Improved Voltage-Shifting-Strategy-to-Attain-Concomitant-Accurate-Power-Sharing-and-Voltage Restoration-in-

Droop-Controlled-DC-Microgrids-IEEE-Transactions-on-Power-Electronics -Year-2021 |-Volu-36,- Issu 2 | -Journal-Article | -Publi-IEEE

16. Weihang-Yan;Lin -Cheng;Shijie-Yan;Wei Gao;-DavidWenzhong Gao -Enabling and Evaluation-of-Inertial-Control for-PMSG-WTG –Using-Synchronverter-With-Multiple-Virtual Rotating-Masses in-Microgrid -IEEE –Transactions-on-sustainable-Energy -Year2020 | -Volum-11, Issu-2 | Journ-Article | Publis-IEEE
17. Sheik M.-Mohiuddin;-Junjian-Qi -Optimal-Distributed-Control of-AC-Microgrids-With Coordinated-Voltage-Regulation and-Reactive-Power-Sharing-IEEE-Trans-on-Smart -Grid Year2022 | Volu-13, -Issu-3 | -Journ-Article |-Publish-IEEE
18. AnkitaSharma;-Bijaya Ketan-Panigrahi-Phase-Fault-Protection-Scheme-for-Reliable Operation-of-Microgrids-IEEE-Transactions-on-Industry-Applications-Year2018 | Volume54, Issu-3 | -Journ-Article | -Publishe-IEEE
19. Yin Xu;Chen-Ching-Liu;Kevin-P. Schneider;-Francis-K. Tuffner;Dan-T. Ton Microgrids for-Service-Restoration to-Critical -Load in a-Resilient-Distribution-System-IEEE-Transactions on-Smart-Grid-Yea 2018 | -Volu- 9, -Issu- 1 |- Jour-Article | -Publis-IEEE
20. Xun-Gong;-XiaozheWang;GezaJoos-An-Online-Data-Driven-Method for-Microgrid Secondary-Voltage-and-Frequency-Control With-Ensemble-Koopman-Modeling-IEEE Transacti-on-Smart-Grid -Yea 2023 | Volu-14, Issu 1 | Journal-Article | -Publi-IEEE