engineering proceedings

MDPI

Proceeding Paper

Linear Quadratic Gaussian Design in Grid Connected and Islanded Microgrid System for Stability Enrichment †

Sureshraj Se Pa *, Mohamed Badcha Yakoob, Muthuveerappan Seetharaman, Jenita D, Kasthuri Arumugam and Srimathi Muthukumaran

Department of Electrical and Electronics Engineering, J.J. College of Engineering and Technology, Poolangulathupatti 620009, India; bashaieee@gmail.com (M.B.Y.); muthueee@gmail.com (M.S.); jenitavictor2020@gmail.com (J.D.); kasthuri18062004@gmail.com (K.A.); srimathimuthukumaran04@gmail.com (S.M.)

* Correspondence: sureshraj2329@gmail.com; Tel.: +91-9710586301

† Presented at the 2nd International Electronic Conference on Processes: Process Engineering—Current State and Future Trends (ECP 2023), 17–31 May 2023; Available online: https://ecp2023.sciforum.net/.

Abstract: This Proposed control design Linear Quadratic Gaussian (LQG) for the Grid-Connected and Is-landed mode—Microgrid composed of one network feeding and forming converter with one local load was designed in this paper. The LQG controller is designed for two different Microgrid modes: Grid-connected mode and Islanded mode. A separate LQG controller was designed for each mode and a comparative analysis was made. The LQG controller was designed using the State-Space variables determined by linearizing the model, controller consists of the optimal gain 'K', optimal Linear Quadratic Regulator (LQR), and the Kalman Filter. In both Microgrid modes, LQG will eliminate disturbance and noise in the system and makes the system optimal control. The Microgrid system also consists of another control system that comprises the subsequent control subsystem, i.e., Alpha-Beta control, Power and Current loop, and Space Vector Modulation. The steady-state response of the Microgrid system, noise, and disturbance present in the Grid-connected and Islanded mode was rectified by the LQG controller. The design Environment used for developing Microgrid and LQG controller is in the MATLAB/Simulink platform. The effective simulations have permitted and determined results that convey the optimal control and stable performance of the proposed system.

Keywords: microgrid; LQG; grid-connected; islanded; state-space; Kalman filter; optimal control; space vector modulation

Citation: Pa, S.S.; Yakoob, M.B.; Seetharaman, M.; Jenita D; Arumugam, K.; Muthukumaran, S. Linear Quadratic Gaussian Design in Grid Connected and Islanded Microgrid System for Stability Enrichment. *Eng. Proc.* **2023**, *5*, x. https://doi.org/10.3390/xxxxx

Published: 17 May 2023

1. Introduction

In the electricity generation, transmission and distribution industry the development was taken in various stages with the recent technologies in the current scenario. The entire infrastructure was commonly referred to as Electrical Power Systems. In the initiation of the 20th century, the electrical environment was ongoing towards the combining of already existing power generation competitors, usually being closer to the end consumers, into large scale state-sanctioned monopolies. A wider move towards the standardized infrastructure and increase in the reliability service was considered to be the main impact on the technology development. This implementation of the recent technologies with the generation units instigated the development path in the Electrical Engineering field. This technology development made formation and enhance the computing network in the electrical power systems to be smarter, efficient, reliable and eco-friendly [1]. Due to the increase in load demand and pressure for Environmentally friendly power generation technologies, the stability between the generation and distribution of power was being taken into consideration. The modern projects relate the concepts of sustainable power and smart cities depend on the grids with more low-capacity distributed generation systems being installed [2].

The main Scenario accounting for the small-scale generation system typical capacity of less than 50 MW, which is being installed nearer to the end consumer Facilities. The Power Generation system acts independently with the Central Load Dispatcher, most probably linked to renewable energy sources, which are Wind Turbines, Solar Photovoltaic Panels Powered systems. The main scope for Distributed Generation system to entitle the formation of a locally connected Generation, Distribution, Consumption Electrical Power System. The essential parameters for distributed generation units are as follows; Energy storage devices and load, effectively handled with a single controllable unit with specific electrical boundaries connecting the main grid. This design mechanism is considered a Microgrid. The Microgrid makes the advantages in Environmental impact and also enhance the local area reliability. It also reduces the risk involved in less capital-intensive infrastructure [3,4]. A Microgrid system mainly characteristics as Flexible and Intelligent, this configuration is commonly classified as per the level of integration with the Main Grid. These classifications are termed Operating modes and they can either be temporary conditions of the Grids or Design Selection [5,6].

The Microgrid can be essentially classified as Grid-Connected and Islanded Microgrid. In this grid-connected mode, the energy importing and exporting process is carried out from the power utility grid for the Microgrid operation and it ensures energy, power control flow balance. The grid is support through an array of Ancillary services. This Ancillary service is namely voltage and frequency control regulation. Based on load and generation conditions another functionality is also being considered [7]. The Microgrids are consistently interlinked to the power utility grid, when there is an excess of energy in the Microgrid it is being sent to the main grid and if there is any energy defect found in the Microgrid then the energy is supplied by the utility grid since the Microgrid must be self-sufficiently designed [8]. This operating mode mainly considers the power utility grid to regulate the network voltage amplitude, frequency and phase at the point of common coupling, that corresponds to the Microgrid and the main grid which is electrically connected.

The converter systems are electronically coupled to the distributed energy sources connected to the one or more loads will normally act as voltage followers in the grid-connected mode they are commonly known as Network-feeding. The Network-feeding are permanently synchronized with the main grid and are aligned to operate proportionally as Current sources when the power electronic converters are constrained to network-feeding [9]. In network-forming, power converters can be used for the control purpose and their work are equivalent to the voltage sources.

2. Microgrid Mode

In this Microgrid design, various operating modes are considered such as a grid-connected mode that is being interlinked with the utility grid, Islanded mode which refers to an autonomous operation are described in the below sections.

2.1. Grid-Connected Mode

The Grid-connected Microgrid operated with the Network-feeding converter and one Load connected to it. The Voltage amplitude, Frequency and Phase are defined from the Utility Grid. Also, the Microgrid Control methods were used to control the Active and Reactive Power which is achieved through adjusting the Modulating Signal from the Control Subsystem as shown in Figure 1.

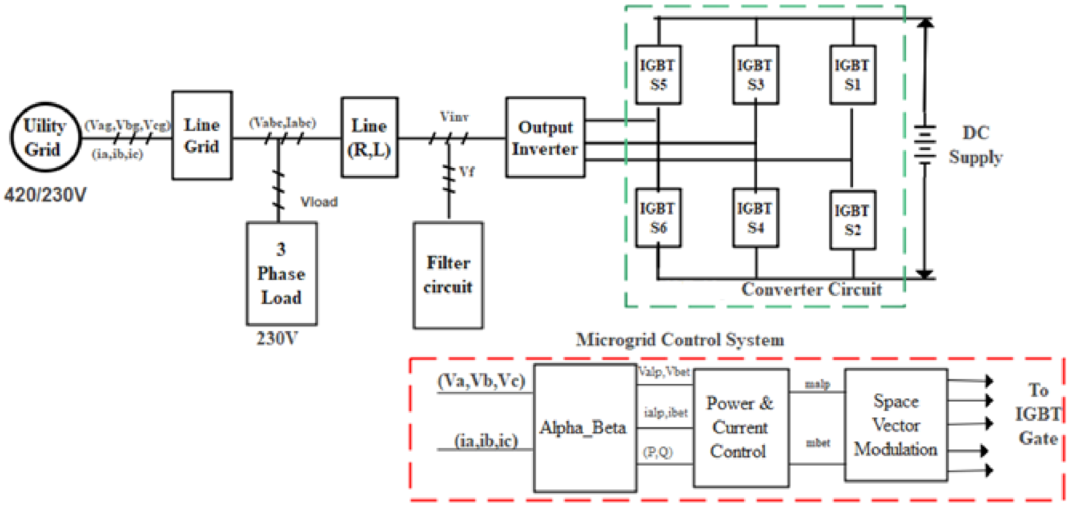


Figure 1. Grid-Connected Microgrid System.

The Microgrid Active Power and Current value can be obtained in the desired range by including Microgrid Control Methods. Here the Microgrid Control system output signal are given to Half-Bridge Converter circuit to control the active and reactive power. A constant DC voltage of 800 V is connected to the Full-Bridge Converter circuit [10].

2.2. Islanded Mode

This Islanded Microgrid operation mode is not connected with the Utility Grid. It is an off-grid representation with inverter operating as the Voltage source. This also includes one local load of voltage range 230 V [10]. The inner current loop and outer voltage loop in the Microgrid Control System are used to determine the desired active and reactive power. The active and reactive power as obtained similar to the Grid-Connected Microgrid system. finally the results were compared in the simulation section. For both the Grid-Connected Microgrid and Islanded Microgrid same control loops are considered.

3. Linear Quadratic Controller Design

For the above designed Grid Connected and Islanded Mode Microgrid System a Linear Quadratic Control is designed to enhance the stability of the Microgrid system.

In control theory environment, the LQG control algorithm is fundamental for optimal control problems. LQG concerns linear systems and acts against the noise reduction in the system for which the Kalman filter algorithm is implemented. This LQG control includes modern state-space techniques to design control and regulator algorithms. This Technique regulates performance and control of the system. The state-space model which includes the Linearized system matrix (A, B, C, D) and (x, u) is the system states and inputs. Here the state space matrix (A, B, C, D) are obtained by linearizing the Microgrid system by using Matlab linearization method. The Grid-Connected and Islanded Microgrid are linearized separately to define the separate LQG controller. Here, the controller gain K is designed at the beginning based on the LQR method. The free parameters Q, R to meet the loop gain and state estimated are implemented by the Kalman filter [11].

The main contribution of Kalman filter is to estimate variables optimally, if it cannot be measured directly. Even though indirect measurement is available. This filter also used to determine the best estimation of states by combining information from multiple sensors in presence of noise.

In this LQG framework, Kalman filter is implemented to eliminate the noise present in the system initially due to the power electronic circuits and also by injecting noise to the system externally.

The LQG control leads the system to optimal and guaranteed closed-loop stability performance. This LQG controller for Grid Connected and Islanded Mode of Microgrid system is given in Figure 2, the LQG Control Framework. In this LQG framework the input signal is injected with white noise is given in to it. The Kalman filter included in the controller will eliminate the noise level present in the signal, further the signal will feed into the first order transfer function and the given to controller gain K, which act to improve the signal stability to the desired range. This is considered as the feedback response from the controller. The free parameters Q and R makes an important role in determining the controller gain K, by tunning the free parameters the sable response of the controller gain can be determined successfully. The LQG control framework is designed separately for Grid-Connected and Islanded mode Microgrid, by linearizing each mode respectively to obtained the state space model. The effective simulation results stating the Grid-connected mode, Islanded mode and LQG Controller response as shown in below section.

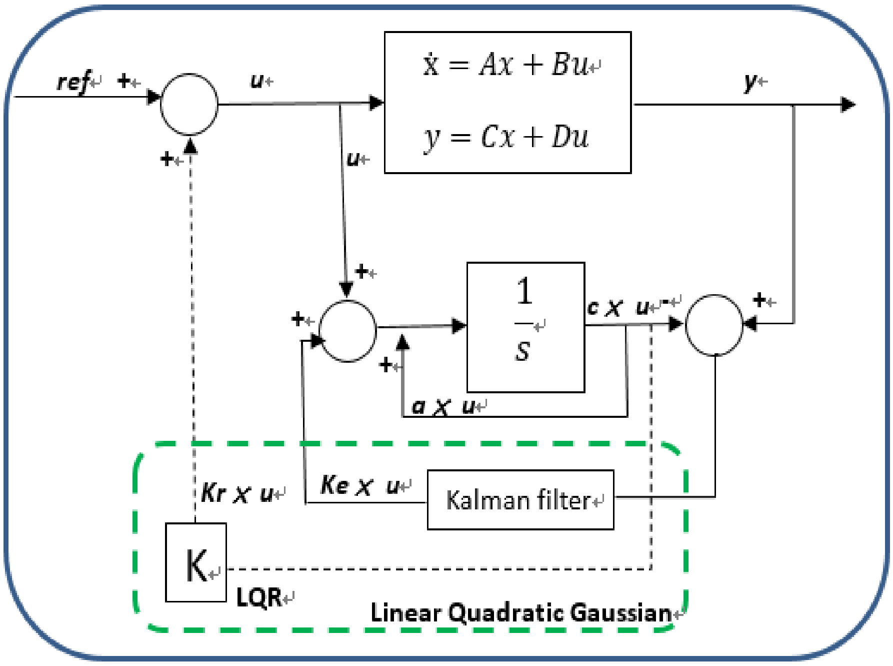
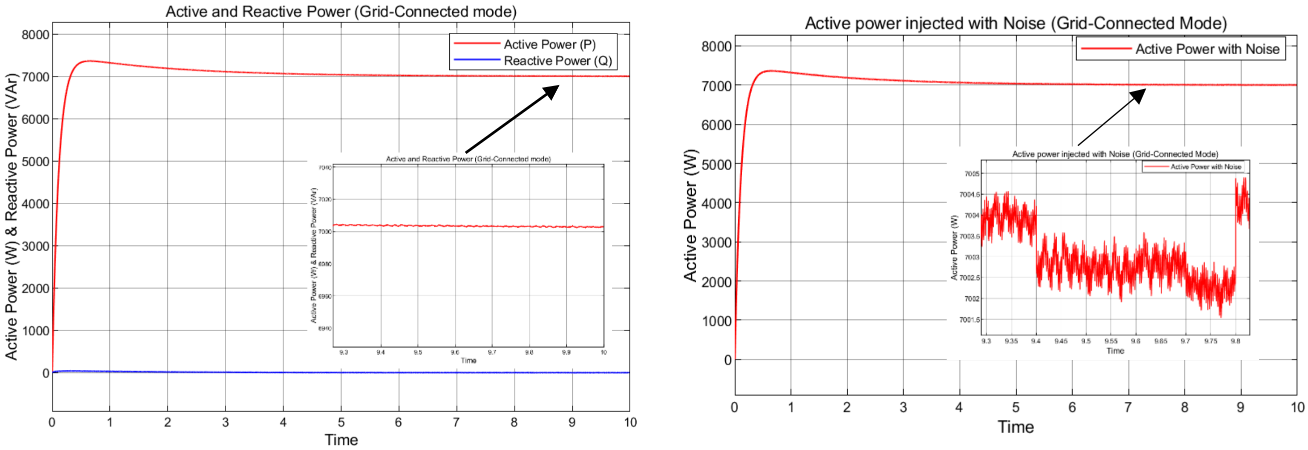


Figure 2. LQG Controller Frame Work.

4. Simulation Results

Grid-Connected Mode

The Active and Reactive Power of the Grid-Connected System is plotted at the values are found to be 7020 Watts for Active Power and 0 VAr (Volt-ampere reactive). In this the elaborated plot shows the disturbance found in the active power which is given in red line, it has the variation 0.4 watts of active power as shown in Figure 3a. The white noise injected to the Active power (P) of the Grid-Connected mode. After the noise injection to active power with the internal disturbance present in the system, makes the power fluctuation range to be higher (i.e., 7003.5 to 7004.6) watt power during the time period of 9.3 to 9.4 s. Furthermore, the fluctuation continued till 10 s with even higher range, it attains a maximum range of 7004.9 at the 9.82 s. This variation in the active power occurs due to the internal disturbance due the power electronic circuits and also by external injection of white noise to the system.



(**a**) (**b**)

Figure 3. (**a**) Active and Reactive Power (Grid-Connected mode), (**b**) Active Power injected with Noise (Grid-Connected mode).

The Active Power with internal disturbance and external noise as in Figure 3b, is given as input to the proposed LQG controller and the LQG response is represented in Figure 4, from this plot it is well understood that LQG with Kalman filter can give a stable response by effectively reducing the disturbance and noise signal. The LQG response is smooth without any overshoot in the signal and it reaches 7000-watt power at time period of 3.8 s.

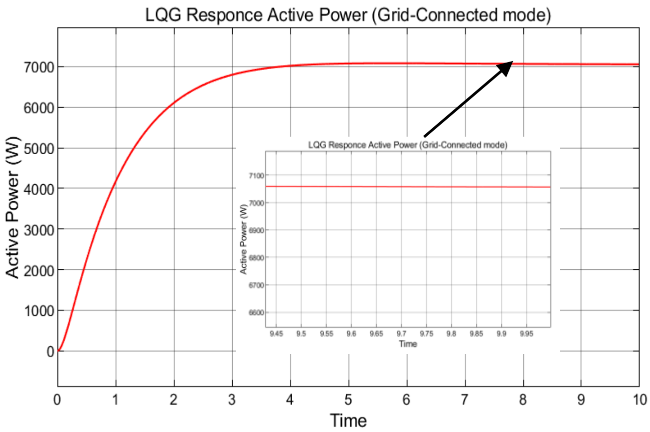


Figure 4. LQG Response Active Power (Grid-Connected mode).

5. Conclusions

This This proposed method includes the Linear Quadratic Gaussian (LQG) control algorithm implemented for Grid-Connected and Islanded mode Microgrid system to reduce the internal disturbance and external injected noise. This LQG algorithm achieves high stable performance against disturbance and noise. The proposed method LQG also includes Kalman filter and (Linear Quadratic Regulator) LQR for noise reduction and also to attain higher loop gain. This method experimented with the active power from Grid-Connected and Islanded Microgrid system and controller leads a better performance by reducing the disturbance range and attains a stable response to the system. This experiment was successfully executed in MATLAB (R19a)/Simulink Environment. Further, this work can be extended to design robust controllers like H-infinity and H_2 norm [12] for comparative analysis of the various controller response.

Author Contributions: Conceptualization, methodology was done by S.S.P., M.B.Y., J.D.; software, validation and formal analysis, S.S.P., M.S.; writing—original draft preparation, S.S.P., K.A., S.M.; writing—review and editing, S.S.P., S.M., K.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. El-Hawary, M.E. *Introduction to Electrical Power Systems*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
2. Cheng, Z.; Duan, J.; Chow, M-Y. To centralize or to distribute: That is the question: A comparison of advanced microgrid management systems. *IEEE Ind. Electron. Mag.* **2018**, *12*, 6–24.
3. de Souza AC, Z.; Castilla, M. (Eds.) *Microgrids Design and Implementation*; Springer International Publishing: New York, NY, USA, 2019.
4. Katiraei, F.; Iravani, R.; Hatziargyriou, N.; Dimeas, A. Microgrids management. *IEEE Power Energy Mag.* **2008**, *6*, 54–65.
5. Khosrow, M.; Kumar, R. A reliability perspective of the smart grid. *IEEE Trans. Smart Grid* **2010**, *1*, 57–64.
6. Rocabert, J.; Azevedo, G.M.; Luna, A.; Guerrero, J.M.; Candela, J.I.; Rodríguez, P. Intelligent connection agent for three-phase grid-connected microgrids. *IEEE Trans. Power Electron.* **2011**, *26*, 2993–3005.
7. Guerrero, J.M.; Loh, P.C.; Lee, T.L.; Chandorkar, M. Advanced control architectures for intelligent microgrids—Part II: Power quality, energy storage, and AC/DC microgrids. *IEEE Trans. Ind. Electron.* **2012**, *60*, 1263–1270.
8. Miret, J.; García de Vicuña, J.L.; Guzmán, R.; Camacho, A. A flexible experimental laboratory for distributed generation networks based on power inverters. *Energies* **2017**, *10*, 1589.
9. Guerrero, J.M.; Chandorkar, M.; Lee, T.L.; Loh, P.C. Advanced control architectures for intelligent microgrids—Part I: Decentralized and hierarchical control. *IEEE Trans. Ind. Electron.* **2012**, *60*, 1254–1262.
10. de Andrade, F.; Castilla, M.; Bonatto, B.D. *Basic Tutorial on Simulation of Microgrids Control Using MATLAB® & Simulink® Software*; Springer Nature: Berlin, Germany, 2020.
11. Hespanha, J.P. Lecture notes on lqr/lqg controller design. Knowledge creation diffusion utilization 2005. Available online: https://d1wqtxts1xzle7.cloudfront.net/36383986/lqrnotes-libre.pdf?1422114167=&response-content-disposition=inline%3B+filename%3DLecture_notes_on_LQR_LQG_controller_desi.pdf&Expires=1683875588&Signature=XXurAsYp9gz~AkDhR4WehbjaZPq~rzqJ-FSAmrRsdZXHWAV0fjUQCffw3ptmQiKua-oedNIq~ZU0HyJIXSJS~wTxg0jBNMgKDRV551C2HRGyaDs9ijJCNzRPFXC7h4YkQurJbr89WVMsqPAN-Jkfi6B57nTcH1Zw8Ej3XafS2sn0-QEtlwogXa-JF5VHnNdcZdWwetA5nJJAFiFkmfO2bSOB~mCzX3~qixFo8mr0jwvjU1xoPrG-MEBHPaph6oRXmTB0zBesyh7mSOCIC6CuCU2g3FiaR7TNsBS6qij5UeGOkOw13n-K3SKWxXKAAZWAQGunzPOO~6xOn00HriklYubwQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA (accessed on).
12. Se Pa, S.; Yakoob, M.B.; Maruthai, P.; Singaravelu, K.; Duraisamy, N.; Palaniappan, R.D.; Pithai, J.B. Machine Learning Gaussian Process Regression based Robust H-Infinity Controller Design for Solar PV System to Achieve High Performance and Guarantee Stability. *Eng. Proc.* **2022**, *19*, 26.