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ROBUST CONTROLLER DESIGN FOR GRID FORMING INVERTER IN AC MICROGRID

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ABSTRACT

With growing environmental concern meeting the exponentially increasing energy demand is a challenging task. Researchers suggest use of distributed energy sources in a Microgrid to tackle this issue. Besides it, this change should be economical and at the same time must not add any concern to growing pollution problem. The use of renewable can serve this purpose but it imposes power quality issues. The objective of this paper is to design robust PI controllers for grid forming inverter to improve power quality. To further improve the performance of the plant, the use of modern control theory based controllers like H infinity mixed sensitivity based controller is also justified by comparing its performance with PI controller.

Keywords: Distributed Energy, H infinity, Microgrid, PI controller, Power Quality

I. INTRODUCTION

These days demand of energy is increasing rapidly. To meet such expending request of energy analysts around the globe are looking for innovative approaches to produce, transmit and disperse energy more efficiently. Electrical energy is a standout amongst the most adaptable types of sources of energy which can be effectively controlled and distributed to end users. The conventional ways of utilizing electrical energy is changing nowadays to curtail losses and inefficiencies associated with existing network [1]. The use of Distributed Generation (DG) is expected to grow more in coming couple of decades [2-4]. The grouping of different distributed generation based sources with loads which go about as solitary controllable entity is called Microgrid. Renewable energy sources are ceaselessly picking up acceptance as far as fulfilling increasing energy demand and reduction of carbon emissions in Microgrid operations are concerned. Amongst different energy sources, the solar energy has touched an impressive development in recent years. The fast acceptance of solar energy is conceivable because of various advantages like, zero carbon emission, less levelized cost of energy etc. associated with it. Amongst different combination distributed energy sources for Microgrid operations, the most encouraging is completely renewable energy based system. Because a completely renewable energy based system emits no CO_2, hence doesn't inflicts pollution problem. Besides it, the existing framework of Microgrid especially in rural areas mostly uses diesel generators. In such systems, diesel generators can be taken out of operation for some time of the day when sufficient amount of solar insolation is available and load can be driven through the use of solar PV panels. But, like other renewable energy sources, solar based energy is intermittent in nature. It causes power quality issues, for example stable reference voltage and frequency for Microgrid is quite challenging to maintain. This issue of voltage and frequency instability needs attention. Now, in one of such cases of an A.C. Microgrid, when it is powered through solar PV panels along with an Energy Storage System (EES), a power converters are required. To maintain stable reference voltage and frequency for Microgrid one power converter can be used in grid forming mode, which is called grid forming inverter. Other power converters can be used in grid feeding or grid supporting mode. The grid forming inverter configuration is investigated in further sections.

An inverter and its controller design is based on some mathematical models. Considering practical systems, the mathematical models of grid forming inverter cannot be a precise replica of actual practical system. The uncertainties in nominal system parameters and random disturbances to the system are inevitable and therefore a converter cannot be modelled with utmost accuracy. The design of practical systems thus necessitates robustness analysis in such systems where disturbances and model uncertainties can affect the system performance and stability. Power system network of present times requires a safe, reliable, resilient and uninterrupted electricity supply. A Microgrid with only renewable energy as the power sources cannot operate within permissible safe limits without proper control schemes. Hence, robust controllers that guarantee stable operation not only for nominal plant but also for perturbed plant are required. Proportional Resonator (PR) controllers are broadly utilized in stationary (ab) reference frame, especially when controlled variables are sinusoidal [5-7]. However, the performance of plant with PI and H infinity mixed sensitivity based controller algorithms for grid forming inverter with same amount of parametric uncertainties is been investigated and compared yet. The objective of this paper is to suggest a PI robust controller for grid forming inverter using repetitive control strategy and proposing an H infinity based mixed sensitivity approach which would be helpful in designing a robust controller to achieve good disturbance rejection from external signals in low frequency region and to limit excitation by noise at high frequency.

II. GRID FORMING POWER CONVERTER

Grid forming power converters act as a voltage source, they have low output impedance and are controlled in closed loop. They work as ideal ac voltage sources with fixed amplitude E* and fixed frequency ω*. They require exceptionally precise synchronization framework to work in parallel with other power converters. Power sharing amongst different grid forming converters connected in parallel is a function of their output impedances. A standby UPS can be viewed as grid forming inverter. A UPS stays detached from the primary network. If there arise an occurrence of any irregularity, for example, grid failure, it forms the grid voltage [9]. A detailed discussion on control of Grid forming inverters is provided by A. Engler and K. De Brabandere et. al [9,10].

In an a.c. Microgrid, the ac voltage generated by grid forming power converter is used as a reference for the other grid feeding converters connected to it. As an example, a controller for a grid forming power converter can realized by using two cascaded synchronous controllers working on the d-q reference frame [8]. The inputs to the control system are the amplitude V* and the frequency ω* of the voltage to be formed by the power converter at the point of common coupling (PCC). The external loop controls the grid voltage to match its reference value, while the internal control loop regulates the current supplied by the converter. Therefore, the controlled current flowing though the inductor L_i charges the capacitor C_i to keep the output voltage close to the reference provided to the voltage control loop. Usually, in industrial applications, these power converters are fed by stable dc voltage sources driven by batteries, fuel cells, or another primary source.

III. SYSTEM MODELLING

Fig. 1 shows a block diagram of cascade control scheme for grid forming inverter. The control scheme for this inverter comprises of two control loops in cascade into the dq referential frame, an outer-loop voltage controller and an inner loop current controller. The outer-loop voltage controller provides a reference for the inner-loop current controller. It needs a phase locked loop (PLL) which provides reference angle for Parkinson’s transformation [8].

Applying KVL, KCL in current and voltage loops, transforming into d-q axis, state space equation for current loop can be written in in following form:

$$\dot{X} = AX + BU \tag{1}$$

$$Y = CX + DU \tag{2}$$

$$\overbrace{\begin{vmatrix} \dot{I}_d \\ \dot{I}_q \end{vmatrix}}^{\dot{X}} = \overbrace{\begin{bmatrix} -R_1/L_1 & -\omega \\ -\omega & -R_1/L_1 \end{bmatrix}}^{A} \overbrace{\begin{bmatrix} I_d \\ I_q \end{bmatrix}}^{X} + \overbrace{\frac{1}{L_1}}^{B} \overbrace{\begin{bmatrix} E_d - & V_d \\ E_q - & V_q \end{bmatrix}}^{U} \tag{3}$$

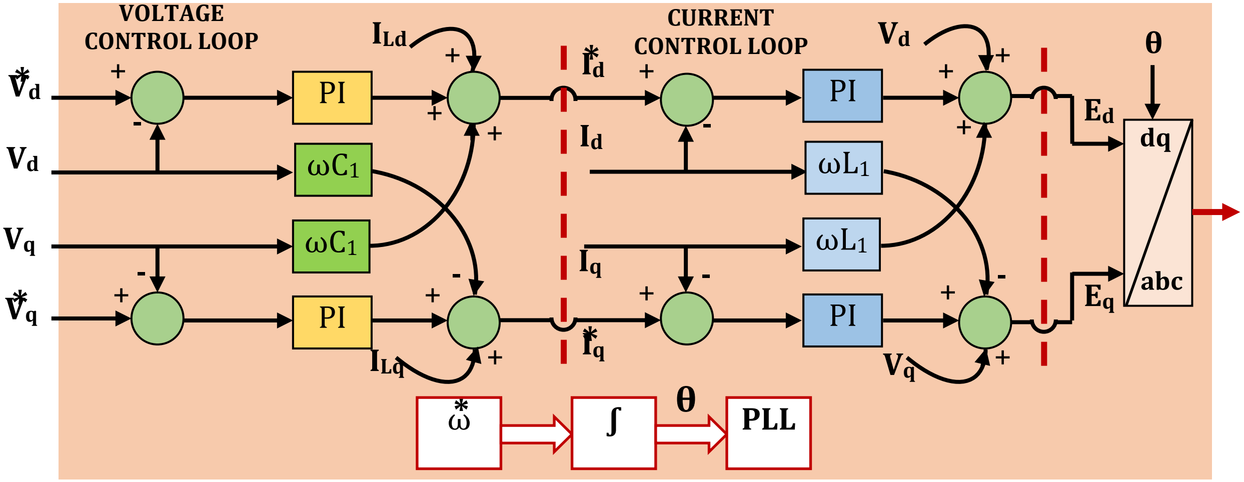

Figure 1: Block diagram of cascade control scheme for grid forming inverter [8]

where, R_i and L_i are current loop resistances and inductances respectively, $\mathbf{E_d - V_d = V_{do}}$ is the reference input for d axis, $\mathbf{E_q - V_q = V_{qo}}$ is the reference input for q axis and $\mathbf{y=I_d}$ is the output for current loop. The discussion in this paper will be corresponding to the current control loop in the grid tried inverter. The voltage control loop can also be designed with the similar approach.

IV. MODELLING UNCERTAINTIES

In a real control system uncertainties are inevitable. Various perturbations that may arise in different parts of a system can be rearranged in a standard configuration of linear fractional transformation F(M,Δ). The standard M-Δ configuration used in robust control theory is shown in fig. 2.

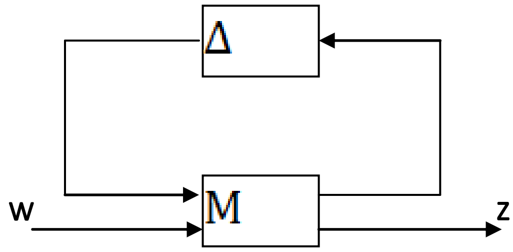

Figure 2: Standard M- Δ configuration

Where, *M* is an interconnection transfer function matrix to let maximum discrepancy in system parameters while modelling uncertainties. The Δ is a triangular matrix whose elements represent percentage variations in different system parameters. And *w* is exogenous disturbance input (reference, noise etc.) and *z* is performance output (This is a virtual output used only for design) [11].

F (M, Δ) is Linear Fractional Transformation of M and Δ. This transformation relates performance output z with exogenous disturbance output *w*. In other words, given percentage variations in system parameters Δ and given matrix M, performance z can be obtained for various disturbances *w*. In case of designing current loop for grid tied inverter, Resistance and Inductance and their percentage variations can be used to obtain the interconnection transfer function matrices M_L and M_R to model the uncertainties in current loop.

1.1 Parametric uncertainty model for current loop:

For current loop as mentioned earlier, uncertainties in R_i and L_i are of main concern. Considering parameters of grid forming inverter as R_i= 0.0345Ω, L_i = 130e-6H and C_i= 2.5e-6μF. Considering, and that R_i and L_i can vary 30% and 20% respectively from their nominal values, the frequency (Bode Plot) and time (Step response) characteristics of open loop uncertain system for current loop are obtained and shown in fig. 3 and fig. 4 respectively.

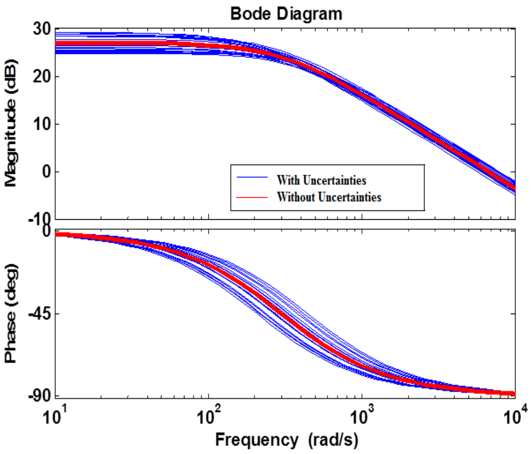

Figure 3: Bode plot for uncertain open loop system (current loop).

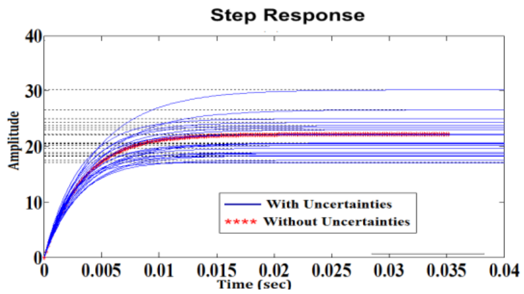

Figure 4: Step response for uncertain open loop system (current loop)

V. ROBUST PI CONTROLLER DESIGN

A controller in d-q reference frame for fast transient response, with minimum overshoot, with minimum steady state error and less system sensitivity to uncertain parameters is desired so that power quality of Microgrid improves along with robust stability. The equations for two axes are decoupled after applying Parkinson's transform analysis for only d axis is considered here and q axis can be similarly obtained.

5.1. Robust PI control for current loop:

A robust PI control for current loop was designed using MATLAB. The resultant step response for uncertainties (as discussed in previous sections) is obtained and the performance is compared. The step response using PI control in current loop for nominal and perturbed plant is shown in fig.5.

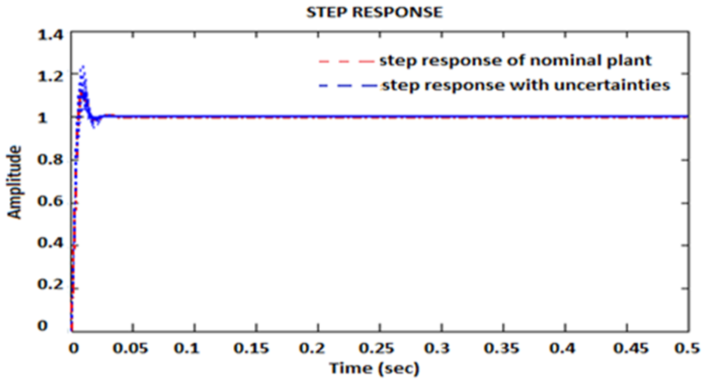

Figure 5: Step response (current loop)

The specifications for this controller are given below:

- For current loop $K_p = 0.0208$ and $K_i = 19.8$.
- The maximum overshoot M_p for this case is 16.6%,
- Rise time t_r is 0.00491 sec.
- Settling time t_s is 0.0251 sec.

5.2. Performance of Robust PI control:

Although, The designed PI controllers for current loop found to be robustly stable, PI controller is causing large overshoot of 16.6% which must be reduced. Therefore, although the plant is robustly stable to the parametric uncertainties, still there is a scope for improvement in its transient response. This improvement can be achieved by applying modern robust control techniques, such as H infinity based robust control.

VI. ROBUST H∞ CONTROLLER DESIGN

The design of control system involves the performance of associated signals in terms of the size of certain signals. One measure of size is norms of the associated signals. One such norm is ∞-Norm. The ∞ norm of signal u(t) is least upper bound of its absolute value [12, 13]. Its physical representation is peak value of signal.

$$\|u\|_\infty = \sup|u(t)| \tag{4}$$

where, '*sup*' represents supremum.

Now, if instead on u(t) a transfer function 'H' is there then the ∞ norm of H appears as peak value on bode magnitude plot of H. the H∞ norm is represented as:

$$\|H\|_\infty = \sup|H(j\omega)| \tag{5}$$

The general H infinity problem synthesis can be represented in fig. 6.

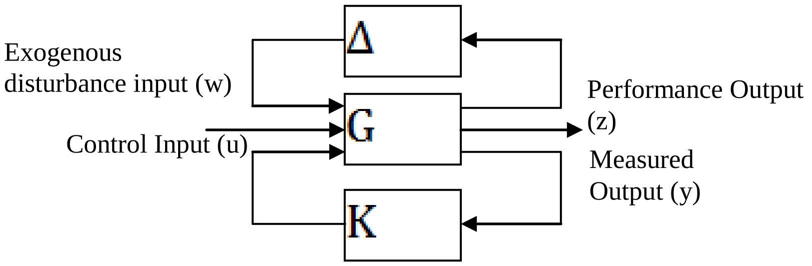

Figure 6: H infinity controller operation

Now, the objective is to find the controller ‘K’. This controller should be such designed that using ‘y’ control input ‘u’ is generated. The control input ‘u’ eliminates the effect of ‘w’ on ‘z’, Doing so means that, the H∞ norm $\|T_{zw}\|_\infty$ will be minimized. This can be written as:

$$\|T_{zw}\|_{H\infty} = \sup_{w \neq 0} \frac{\|z\|_{L2}}{\|w\|_{L2}} \tag{6}$$

6.1 Frequency Dependent Weighing Matrices:

Further, frequency dependent matrices W_1 to W_3 are used for the augmentation of the plant G (fig. 7) to achieve required design objective over frequency range along with the minimization of H∞ norm. W_1 must have characteristics which resembles with that of low pass filter and W_2 with that of high pass filter. S and T in fig. 7 are sensitivity and complementary sensitivity function and matrix R does not have any common name A detailed discussion on H∞ controllers can be found in G. Murad et al and D. J. N. Limebeer et al [12, 13]

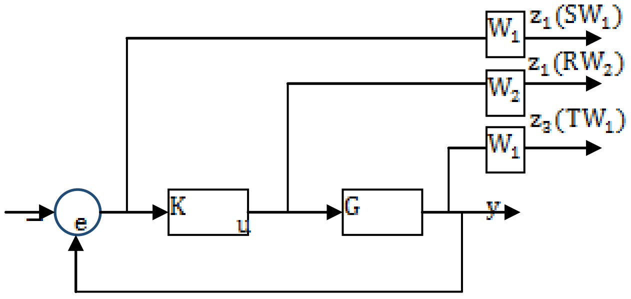

Figure 7: General H infinity problem synthesis with weighing functions

6.2 Stepwise procedure for H∞ control design for current loop:

Proposed Robust H∞ control design for current loop should have the following main steps:

- The state space equation for current loop is shown in equation (3). Using it, with required uncertainties in different parameters, the LFT model for current loop will be obtained as shown in fig.2.
- From LFT model of fig. 2, the system equations will be expressed in following form:

$$\dot{x}(t) = A\,x(t) + B_1 w(t) + B_2 u(t) \tag{7}$$

$$z(t) = C_1\,x(t) + D_{11} w(t) + D_{12} u(t) \tag{8}$$

$$y(t) = C_2\,x(t) + D_{21} w(t) + D_{22}\,u(t) \tag{9}$$

where A, $B_1, B_2, C_1, C_2, D_{11}, D_{12}, D_{21}, D_{22}$ are matrices containing system parameters R_i and L_i

- The next step is to select appropriate weighing functions. Weighing functions are required in S over T design of H∞ control.
- The H∞ based controller can then be obtained. Functions for H∞ control are available in MATLAB and can be utilized for the controller design.

VI. CONCLUSION

The objective of designing the controllers in d-q referential frame is to produce no steady state error, minimum overshoot and fast response. The performance of PI control can be improved by H infinity based mixed sensitivity approach. More than one cost function can be minimized using mixed sensitivity technique. The sensitivity function *S* and Complementary sensitivity function *T* can be used for *S* over *T* design to achieve good disturbance rejection from external signals in low frequency region and to limit excitation by noise at high frequency. The same procedure can be repeated for both q and d axes of both current and voltage loops.

REFERENCES

[1] C. Feisst, D. Schlesinger, and W. Frye, "Smart Grid, The Role of Electricity Infrastructure in Reducing Greenhouse Gas Emissions", Cisco internet business solution group, white paper, October 2008.

[2] B. Michlon, A. Nejmi, J. DosGhali, A. DahmanSaidi, and J.C. Bolay, Electrification of isolated areas by interconnecting renewable sources: a sustainable approach, IEEE int. conf. on Clean electrical power (ICCEP), Capri, 2007, 33-40.

[3] D. Xu, L. Kang, L. Chang, B. Cao, Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithm, Canadian Conference on Electrical and Computer Engineering, Saskatoon, Sask., 2005, 1722-1727.

[4] S. Paudel, Optimization of hybrid PV/wind power system for remote telecom station, Int. Conf. on Power and Energy Systems (ICPS), Chennai, December 2011, 1-6.

[5] J. G. Hwang, P. W. Lehn, and M. Winkelnkemper, A Generalized Class of Stationary Frame-Current Controllers for Grid-Connected AC–DC Converters, IEEE Trans. on Power Delivery, 25(4), 2742- 2751, 2010.

[6] S. Guoqiao, Z. Xuancai, Z. Jun, and X. Dehong, A New Feedback Method for PR Current Control of LCL-Filter-Based Grid-Connected Inverter, IEEE Transactions on Industrial Electronics, 57(6), 2033-2041, 2010.

[7] M. Liserre, R. Teodorescu, and F. Blaabjerg, Multiple harmonics control for three-phase grid converter systems with the use of PI-RES current controller in a rotating frame, IEEE Trans. on Power Electronics, 21(3), 836-841, 2006.

[8] A. M. Bouzid, P. Sicard, A. Chériti, H-infinity loop shaping controller design of micro-source inverters to improve power quality, IEEE 23rd Int. Symposium on Industrial Electronics, 1-6, May 2014, 2371-2378.

[9] A. Engler, Control of inverters in isolated and in grid tied operation with regard to expandability in tutorial: Power Electronics for Regenerative Energy, Proc. IEEE Power Electron Special Conf., Aachen, Germany, 2004.

[10] K. De Brabandere, B. Bolsens, J. Van den Keybus, A. Woyte, J. Driesen, and R. Belmans, A voltage and frequency droop control method for parallel inverters, IEEE Trans. Power Electronics, 22(4), 1107-1115, July 2007.

[11] D.-W. Gu, P. Hr. Petkov and M. M. Konstantinov, Robust Control Design with MATLAB® (Verlag, London: Springer, 2005).

[12] G. Murad, I. Postlethwaite, D. W. Gu, and R. Samar, On the structure of an H∞ two degree of freedom internal model based controller and its application to a glass tube production process., Proc. Of 3rh European Control Conf., Rome, September 1995, 595-600.

[13] D. J. N. Limebeer, E. M. Kasenally, and J. D. Perkins, On the design of robust two degree of freedom controllers, Automatica, 29, 157-168, 1993.