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Conclusions and Future Work

The thesis has proposed solutions for the stabilization and assurance of the required performance for different dc/dc converters and island PV based dc microgrid in the presence of constant power load. Stability has been ensured in large-signal sense and limit on CPL power has been obtained. Robust sliding mode control approach has been used to mitigate the destabilizing effects introduced by CPLs. Simulation studies and experimental results have been presented to validate the proposed theoretical developments. This chapter concludes findings of the work and proposes possible work required for future research. Thesis started with introduction to dc distribution systems, CPL and its behaviour, stability of dc/dc converters and islanded dc microgrids with CPL, a brief review of the literature, the motivation behind the proposed work, research objectives and organization of the thesis.

Mitigation of negative impedance instabilities in a dc/dc boost converter feeding a total load of CPL nature has been addressed using a PWM based SMC with a nonlinear switching function. When total load is of CPL nature, it represents a worst case scenario from the stability point of view. It has been shown through simulation studies and experiments that the proposed SMC is effective to mitigate the destabilizing effects of CPLs. It has been found that with the proposed controller the output voltage is sensitive to large variations in the input voltage. Although the switching function is computationally less intensive, it is sensitive to the variations in the input voltage. Therefore, the proposed controller is more suitable for applications where supply of constant power is a primary requirement and regulation of dc bus voltage is not crucial. In order to incorporate voltage regulation capability and enhance robustness to the input voltage variations, a modified nonlinear switching function was proposed. The modified switching function was then used to design a discontinuous and a PWM based sliding mode controller. A limit on the CPL power has been established to ensure the system stability. It has been shown through simulation studies and experimental results that the destabilizing effects introduced by CPL can be mitigated through the application of these sliding mode controllers derived with modified switching function. Furthermore, the modified nonlinear switching function based discontinuous SMC is applied to a dc/dc boost converter with resistive load to emulate dc CPL behviour accurately. A programmable CPL is needed to test the dynamics of supply sources and dc/dc converters. The effectiveness of the emulated dc CPL has been validated through simulation studies and experimentations. It has been found that emulated dc CPL consumes constant power from its source, in different operating conditions, and under sufficiently large variations in the input voltage. The emulated dc CPL is simple in design, has fast transient response, and offers a cost effective way to test supply sources and power electronic converters, intended to feed CPLs.

The application of sliding mode controller derived using modified switching function was then extended to a dc/dc buck converter feeding a mixed load (resistive and CPL). The condition for large-signal stability was established and a limit on total power has been obtained to ensure the system stability. Despite the significant differences in the dynamic behaviour of boost and buck converter, it has been shown that the proposed discontinuous and PWM based sliding mode controllers can successfully mitigate the destabilizing effect of CPL in the dc/dc buck converter feeding a mixed load. To validate the performance of the proposed controllers simulation studies using $MATLAB/SIMULINK^{TM}$, and experimental results with controllers realized through NI GPIC FPGA (XILINX Spartan 6) card, have been presented under different operating conditions. A new switching function has been proposed to design robust SMC to mitigate the destabilizing effects of CPLs in dc/dc buck-boost converter feeding a composite load. In this case also, a condition for the stability of the system has been established. It has been shown through real-time simulation studies that the proposed SMC can effectively mitigate the CPL induced destabilizing effects in buck and boost mode, and under sufficiently large variations in the supply and load. Mitigation of the destabilizing effects of CPLs was then addressed in a bidirectional buck-boost converter feeding a CPL dominated load, in a typical DCMG application. A robust sliding mode controller has been proposed which ensures dc bus voltage regulation and system stability under charging and discharging mode of operation of BDC. The performance of the proposed SMC has been validated through real-time simulation studies using ORDS and it has been shown that the controller ensures dc bus regulation within tight limits and robustness to the sufficiently large variations in the net power demand.

After addressing mitigation of the destabilizing effects of CPLs in individual dc/dc power converters, the work advanced in the direction of a practical dc distribution system, with many power converters, renewable energy sources, storage units, and serving a diverse load profile. In this direction, mitigation of CPL induced instabilities and dc bus voltage regulation in an islanded dc microgrid have been addressed using robust SMC approach. Sliding mode controllers using novel switching functions have been proposed for RES interfacing converters and battery energy storage interfacing BDC, to mitigate the destabilizing effects of CPLs in a generalized PV based islanded DCMG feeding a composite load, representing the load profile of a practical dc microgrid. A limit on the CPL power to ensure stable operation has been established. The proposed control scheme is validated through real-time simulation studies using OPAL-RT Digital Simulator under a wide range of operating conditions. The proposed control scheme has been found to be robust with respect to variations in the input voltage, system parameters, and the load. And finally, mitigation of the destabilizing effects of CPL and robust control of a prototype PV based dc microgrid realized in the laboratory have been addressed. The dc microgrid consists of two solar PV arrays interfaced through dc/dc boost converter, energy storage unit interfaced through a bidirectional dc/dc converter, and load (resistive load, programmable CPL, and a speed controlled dc/ac inverter drive). Furthermore, a charging/discharging algorithm has been incorporated in the controller of BDC which facilitates three modes charging of the battery energy storage unit, to enhance its life and performance. The performance of the proposed robust control scheme has been validated though simulation studies and experimentations under various operating conditions. It has been shown that the application of the proposed nonlinear control scheme mitigates the destabilizing effects of the CPLs and enhances the robustness of the system to the parameters, supply and load variations. It has also been shown that the proposed control ensure voltage regulation of less than 5%. To demonstrate the performance of the implemented charging/discharging algorithm for bidirectional dc/dc converter, experimental results have been obtained showing its operation in different operating modes. Although, the test system had two RES converters and one BDC, the proposed theory can be extended to a dc microgrid with any number of converters.

Thus, the Thesis addressed mitigation of the destabilizing effects introduced by CPLs in basic non-isolated dc/dc converters and the islanded dc microgird through nonlinear control technique based on SMC approach. The application of robust sliding mode control approach can enable a reduction in dc bus capacitance size to stabilize the system in the presence of CPLs, resulting in a reduction in the overall size and cost of the system.

RECOMMENDATIONS FOR FUTURE WORK

The present work has addressed mitigation of the destabilizing effects introduced by CPLs in the basic non-isolated topology dc/dc converters and PV based islanded dc microgrids using robust sliding mode control. Much research is further required to take presented work forward. To ensure resiliency in dc microgrid operations, a few recommendations for future research are as follows

In this work, robust sliding mode control approach has been used to mitigate negative impedance instabilities introduced by CPLs in non-isolated topology dc/dc converters and their integrated system, in the form of an islanded dc microgrid. This approach can be extended to mitigate the destabilizing effects of CPLs in new topologies of dc/dc converters e.g. isolated and multilevel dc/dc converters. Sliding mode control based nonlinear control proposed PV based dc microgrid need to be extended to MPPT controllers for RES converter and controller of grid-connected bidirectional VSC, and the study of the performance of the control scheme in different operating modes of the microgrid under high penetration of CPLs. Furthermore, the application of robust nonlinear control can be extended to a generalized dc microgrid, including other renewable energy sources (e.g. wind turbine, fuel cells) with high penetration of CPLs, to design robust sliding mode control scheme, to ensure stability and dc bus voltage regulation in different islanded and grid-connected operating modes. Mitigation of the destabilizing effects introduced by other nonlinear loads such as pulse power loads (a typical behaviour shown by electric vehicles in charging station dc microgrid) using the robust sliding mode control is also one of the possible research directions.

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