CHAPTER 7

CONCLUSIONS

7.1 SUMMARY

The objective of this research work is to design, fabricate and test a single stage grid connected PV inverter to transfer power from PV array to a micro-grid, with Maximum Power Point Tracking capability under all ambient conditions including partial shading conditions. Furthermore, the so developed converters are to be tested under extreme ambient conditions using a PV emulator. The major conclusions of this research work have been presented in different chapters. A summary of good things surfaced during the research is presented as conclusions and suggestions for future work in this section.

For different renewable energy conversions maximum power point tracking (MPPT) algorithms are available which are realized through additional converter stages. When it comes to the control of single stage VSI, then the existing iterative MPPT algorithms turn out to be unsuitable for direct use in inverter control. Also they require large convergence time before reaching the MPP with reported oscillations around the optimum operating point due to their iterative nature. This issue is addressed in the research work and was presented in chapter 4.

Next is a quick recap of the issues in the control of VSI in micro-grids. The observations on the performance of SRF-PI controllers, when used for control of VSIs in micro-grids, identified with inadequacies such as interdependency of active-reactive power controls and poor system stability. Thus a dynamic intelligent controller with superior d-q axis decoupling which was leading to better system stability when working with micro-grid was developed and the details were presented in chapter 6.

Testing of the power converters developed is of major concern, as they are to work in synchronization with the grid, which will have all arbitrary non-idealities. Moreover, the input side of these converters is connected to an intermittent energy source, which mandates the repeated testing of these converters for their consistent performance with every grid and ambient condition. A real-time hardware infrastructure, in short, an emulator is essential for this purpose instead of PV panel as they are nature driven, it is difficult to set repeated conditions. The inadequacies in the existing PV emulators like not accounting ambient conditions, requiring large memory, inability to obtain all the operating conditions etc., were kept in mind for the development of a new PV emulator referring to section 5.

7.2 INFERENCE FROM THE RESEARCH WORK

The first level of research work includes the design, development and hardware implementation a novel non-iterative maximum power point tracking (MPPT) method for grid connected VSI.

The power at maximum power point is obtained by sensing the V_{OC} and I_{SC} online from the panel during operation. A sinusoidal band hysteresis current controller receiving the current reference calculated from the P_{mpp} has been used for switching the inverter. The developed MPPT algorithm has been tested with a 500 W PV array feeding a 1 kVA three phase inverter and the results from the experimental setup for different irradiance conditions had been presented and verified. A partial shading condition was deliberately created so as to verify the effectiveness of the developed OC-SC value based

MPPT algorithm. The power measurements at the PV panel output and the inverter output showed a reduction of only 4% compared to the datasheet values under partial shading conditions. The power values found from the developed MPPT algorithm is verified by conducting conventional load tests and compliance is confirmed. The convergence speed of this algorithm has been found to be 0.6ms, a superior figure, as it is a non-iterative method of MPPT and the oscillations around the optimum operating point were not felt. This algorithm was implemented with the SRF current controller of chapter 3 to provide active power reference for the inner current loop.

A model based hardware PV simulator has been built and tested in the laboratory for testing of the designed power converters under repeated ambient conditions. The simulator uses a mathematical model that can be tailored to match any commercially available panel. The model based simulator gives *i-v* characteristics as that of any PV panel at any specified ambient conditions. The ambient conditions, as required by the operator can be entered into the simulator system. As a test case the published data of 115W solar panel Shell S115 has been used to build the simulator. The prototype has been tested in the laboratory for steady-state and transient conditions of insolation and load. The experimental data and the data sheet values are matched using a 9^{th} degree polynomial curve fit, and the deviation between them is found to be 0.5 % to 1.5 % for different insolations.

For the shortcomings observed in the SRF PI current controller in micro-grid a dynamically decoupled current controller using online grid impedance value has been designed and developed in the present research. The developed online grid impedance based dynamically decoupled current controller exhibited a better d-q axis decoupling capability because of the use of the accurate impedance value for decoupling. This was achieved by continuously measuring the grid impedance and updating the control loop with new values every time. This decoupling allowed independent control of active and reactive powers against step changes in their active/reactive power references even during a change in the network configuration in the scale down micro grid. This made the control insensitive to the system parameter uncertainties in the micro grid. Here the grid inductance has been measured during the operation using a non-characteristic frequency current continuously injected into the grid, which avoided the generation and injection of inter-harmonics into the grid while measuring. The decoupled controller with grid impedance measurement has been tested through simulation studies and also by experiments and the results were presented separately. The influence of source inductance mismatch on decoupling and subsequently the active/reactive power delivered has been presented using simulations, with the use of nominal value of ωL for decoupling. Experiments were conducted with the developed dynamically decoupled current controller controlling a 3 phase 1kVA inverter synchronized to the scaled down laboratory model of micro-grid. The experimental set up has been tested by introducing step changes in the active and reactive power references, and it has been concluded that these transitions from one power level to another has been very smooth and the controller track the d-q current references with nil steady state error, with a current THD of only 4% is slightly better than the specification figure of 5%. Also the introduction of sub-harmonics due to the non-harmonic injection has been greatly reduced due to the continuous injection. As the control loop is loaded with the actual 'ωL', the system transfer function remained constant, and this resulted in a stable control loop throughout the operation irrespective of the configuration or reference changes.

7.3 FUTURE SCOPE

- A small deviation in the OC and SC constant values under partial shading conditions can be tackled by incorporating a hill climbing iteration of the reference current from the calculated value as a future progression of the algorithm. The convergence speed will not be affected as there is an initial knowledge of the maximum operating point at the start of iteration with this MPPT unlike in other MPPTs they start from a random operating point.

- In the SRF current control, the *abc-dq* transformation is executed based on the assumption that the voltage at Point of Common Coupling (PCC) contains only fundamental component. If the voltage at PCC has harmonics, then the *abc-dq* transformations should be done with multiple reference frames each for one frequency components. Though it makes the computations laborious gives better accuracy in accounting the harmonics.

- The harmonic problem can be addressed by introducing a Proportional Resonant (PR) controller in the control loop instead of a simple PI controller. A PR controller has the feature of infinite gain at one tuned frequency, which can be the grid frequency. Also it has provisions for adding selective harmonic compensators in its control loop, which can reject the selected harmonics even if it is present in the grid. The main advantage of PR is that it operates with stationary reference frame, whose conversions are immune to multiple frequency components even if they are present at PCC.