Chapter-1

Introduction
1.1 Introduction

Conventional power system is turning to be increasingly complex to deal with consistency in operation and control to the increased power demand, reliability requirement due to the rapid expansion of power grid network, decline in the availability of primary energy, customary and aged electrical transmission and distribution networks [1]. As a result to find solution for the above issues in the last few years, new resolutions such as distribution resources (DR), microgrid (MG), active demand management (ADM), and electrical energy storage (EES) have emerged as future works to accomplish. DR integration to the distribution sector is a promising effort in this direction to cope up with these problems as it has many operational advantages over conventional grid such as: 1) improves system stability, 2) reduces transmission and distribution losses thus increasing the efficiency, 3) reduces environmental pollution and global warming through utilization of low carbon technology, 4) can supply uninterruptable power, 5) supports local power grid and helps in generation augmentation thereby improving overall power quality and reliability.

Existing distribution system are designed and established with an assumption of power flow in a unidirectional mode of operation from the substation to the load [2]. However the integration of distribution resources (DR) on a distribution feeder, changes the concept of unidirectional power flow approach of design to a bidirectional structure. Without careful engineering, DR penetration can potentially have many adverse system impacts related to protection, control, power quality, reliability of power supply, restoration time after outage and operational safety [1]. Further development and careful engineering design can effectively eliminate those potential adverse impacts that DR penetration could impress on the electric delivery systems, Apart from the above system issues there are other issues related specifically on DR operation which has to be emphasized for an overall ideal system.

Distributed energy Resources (DER) encompasses a wide range of prime mover technologies such as internal combustion (IC) engines, gas turbines, and micro turbines,
photovoltaic (PV) systems, fuel cells, wind power and ac storage. However, most emerging technologies such as micro turbines, PV systems, fuel cells and ac storage have an inverter to interface with the electrical distribution system. Looking to the rapid implementation at recent time and possible benefits which can be harvested after implementation the two DER, PV and fuel cells are taken for further study in this work. Furthermore, with the use of individual distributed generators, it is hard to resolve any of the issues completely due to complexity of the microgrid structure, a hybrid study comprising of PV and fuel cells are further exploited in this work.

Broadly on the basis of technical issues associated with control and protection, the major challenges of DR integration to microgrid can be segregated into four types as presented in Fig.1.1. Out of the four issues, controlling the power in both DR level and system level are taken into consideration which further enhances the stability, voltage, power quality and reliability of operation. At DR level maximum power point tracking (MPPT) control has been focused as the input energy is mostly dependent on environmental conditions. So it is necessary to abstract the maximum energy possible from the existing resources. This in turn helps to manage the power according to the load demand and better power management. As an addition to power control at system level, power sharing control is further focused for smooth control of power with satisfactory system stability and reliability. An attempt has also been made to improve the control of power subjected to various system constraints like voltage and frequency limit by joint integration with energy storage devices and FACTS device.

![Major Challenges of DG integration to microgrid]

Fig.1.1: Topology for major challenges of DG integration to microgrid

1.2 Background

The microgrid architecture model can be classified into three main groups depending on the way in which the ac and dc buses are connected such as: ac microgrids, dc microgrids and hybrid ac-dc microgrids. AC microgrids integration to conventional ac grids is easy due to most of loads and grid being ac in nature. However the connection of dc loads, dc sources
(PV and fuel cells) and energy storage devices are connected to the ac bus via dc/ac inverter. This causes a significant decrease in efficiency and increase in complexity in power control. Therefore it is an alarming situation for existing microgrid distribution system with DR integration to achieve more capacity, controllability and flexibility to the system. Looking to the extensive ac microgrid applications the present study investigates the distribution system with distributed generations (DG), energy storage and FACTS devices in various angles pertaining to power control.

As mentioned from the above discussion, DG technologies require power electronics interface with adequate control strategy in order to convert the energy into grid compatible ac power or directly to ac and dc loads. The power electronics interface not only contains the necessary circuitry, but also robust control strategies to convert power from one form to another. In the recent past, different types of converters are suggested and some of them are implemented like: single stage converter (dc-ac converter) or a double stage converter (dc-dc and dc-ac converter) for smooth operation. Another component the power converters need to be integrated for improving harmonic performance at lower switching frequency, particularly is the output filters (L, LC, LCL and LCL with damping resistor) being connected in series with the converters. The above related factors to converters are taken care of throughout the work along with the proposed controller for smooth power transfer.

For any microgrid the DG’s must be rightly selected according to their characteristics, cost of different technologies, environmental factor and requirement of microgrid upgradation. Out of various possibility of DG integration, the PV based DG is considered due to its capability to enhance the following aspects of microgrid control like: reactive power support and voltage control, active power and frequency regulation, dynamic regulation such as Low Voltage Ride–Through (LVRT) and fault-ride through ability, and power quality enhancement, etc. However due to environmental dependent energy input resource, it is difficult to operate the system with high reliability under unpredictable load variation. So hybrid microgrid system is taken into analysis along with fuel cells as an auxiliary support. Hence with an assumption that PV as the primary source of generation and fuel cell as backup support source of generation, all the proposed methods are tested and analysed. Even if actual microgrid structure is very complex and different structure, more stress has been emphasised on the performance of proposed methods restricted to microgrids containing PV and fuel cells only. Apart from that the study encompasses from low voltage to high voltage distribution systems in both grid connected mode and isolated mode of operation.
Real environmental conditions for a PV system may force to operate under rapidly and randomly changing irradiance and non-uniform distribution of temperature and irradiance across the cells due to shadow from objects or due to internal mismatch between the modules. In addition to the above the overtime cell degradation may affect and change the system operation. It has been found that these conditions result in the need for a technique that can abstract the absolute maximum power under this potentially highly variable and non-uniform conditions. Taking these practical issues as a primary objective with related criteria and constraints at the implementation stage of PV, this study focus to develop an appropriate control for gaining better MPPT.

Proper power management in microgrid with available multiple DG power sources is possible by proper power sharing control taking various related limits and constraints. Improper power sharing affects frequency and voltage with slow transient response, unbalanced sharing of harmonic currents and negative affect by inverter input impedance or line impedance. The associated drawbacks to overcome need an improvement to the conventional droop methods. The present study focuses on this issue with an objective to formulate a better approach to reduce the negative factors towards having a better power sharing.

To smooth out or shape the power provided by the DG’s to the loads in the distribution system maintaining high reliability and power quality, the integration of energy storage devices is required. Generally the inverter based ac storage can be integrated to the microgrid without any inverter provided the fast response and voltage control through reactive power injection, etc is achieved. Specific to the islanded PV microgrid, power levels may be greater than the loading and under this circumstance either high storage capacity is needed to absorb the extra energy or have methods of reducing the power output of the solar panel. Apart from that during excess generation, the increase in frequency automatically reduces by pushing the storage devices to a charging mode and act as a back up source to the PV output during off peak period. However, energy storage devices in microgrid can be utilized with an objective to improve power imbalance, power quality, reliability and stability between loads and distributed generated resources output. Choice of suitable energy storage devices mostly depends on the characteristics of load and the distributed energy resources, apart from these factors its own characteristics, cost factor and control aspects plays a major role to gain the merits as mentioned above. Out of the many available energy storage devices, the supercapacitor is chosen on the basis of its greater operational benefits [3].
Static synchronous compensator (STATCOM) is utilized in distribution sector as a source and sink of reactive power. These FACTS (flexible ac transmission system) compensating equipments are additional electronics devices that are used to regulate power profile within permissible levels maintaining high voltage and frequency regulation and better voltage control by reactive power management in distribution system [4]. However, the use of STATCOM in distribution sector is generally as shunt active power filter and used as power quality conditioner to alleviate power quality issues caused by PV integration. These factors make us feel to investigate further to enhance the system performance by the multi-directional benefits of DSTATCOM (Distribution-STATCOM).

The power control tasks can be sub-divided into two major parts. The control of source side controller aims to extract the maximum power from the input source. So the initial part of the work stresses upon to operate under MPPT mode by designing proper control strategy for the associated inverters under various operating conditions. Later on, the work is progressed with the control of grid side controller, which aims to control both active and reactive power transfer ensuring high power quality and dc-link voltage control. The study is further extended to enhance the operation stability and control in association with energy storage and FACTS devices. A hybrid microgrid structure with both PV and fuel cells are taken to test the proposed techniques, and almost similar system to real time distribution microgrid structure.

1.3 Literature Review

Recent publications related to this problem are reviewed and summarized in this chapter which are organized in two sections, as follows:

1) The first section reviews the literature on various MPPT control techniques. A brief background of conventional MPPT techniques is presented, followed by a thorough review and summary of the literature along with their limitations.

2) The load sharing control problems are reviewed in the second section. Recent work on power sharing techniques are analyzed and reviewed.

1.3.1 On MPPT Control

MPPT is a technique to track the maximum power point of PV arrays and it is mandatory for the improvement of the system efficiency. MPPT trackers operate
continuously to compute and to ensure the optimum power delivery from a PV system irrespective of the load, temperature or irradiance variation. Operationally on the control aspect point of view, the MPP trackers are power electronics based dc-dc converters with varying duty cycles and a pulse width generator. In general the pulse width generator is applied to generate pulses matching to a voltage reference in the MPPT system which in turn operate the PV panel to deliver its maximum output power continuously. With the change of system load and even under random changes in external conditions the PV system is capable to yield the maximum output power by moving its operating point by an appropriate controller. Here the trackers are considered as a part of the PV inverter control system. Various authors have proposed several techniques for MPPT. Subject to our interest the classical and soft computing based techniques are enumerated and compared mentioning their operational characteristics, advantages and limitations in Table 1.1.

Table 1.1: Comparison of different MPPT techniques according to their type of classification

<table>
<thead>
<tr>
<th>MPPT based Control</th>
<th>PV Array Dependent</th>
<th>Convergence Speed</th>
<th>Implementation Complexity</th>
<th>Periodic Tuning</th>
<th>Algorithm Complexity</th>
<th>Response Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Techniques</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perturb &amp; Observe (P&amp;O) [5-12]</td>
<td>No</td>
<td>Varies</td>
<td>Low</td>
<td>No</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>Incremental Conductance (INC) [13-19]</td>
<td>No</td>
<td>Varies</td>
<td>Medium</td>
<td>No</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>Fractional Open-Circuit Voltage [20-24]</td>
<td>Yes</td>
<td>Medium</td>
<td>Low</td>
<td>Yes</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>Fractional Short-Circuit Current [25-29]</td>
<td>Yes</td>
<td>Medium</td>
<td>Medium</td>
<td>Yes</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>Ripple Correlation Control (RCC) [30]</td>
<td>No</td>
<td>Fast</td>
<td>Low</td>
<td>No</td>
<td>Moderate</td>
<td>Slow</td>
</tr>
<tr>
<td>Current Sweep [31]</td>
<td>Yes</td>
<td>Slow</td>
<td>High</td>
<td>Yes</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>DC-Link Capacitor Droop Control [32-33]</td>
<td>No</td>
<td>Medium</td>
<td>Low</td>
<td>No</td>
<td>Moderate</td>
<td>Slow</td>
</tr>
<tr>
<td>Load Current or Load Voltage Maximization [34]</td>
<td>No</td>
<td>Fast</td>
<td>Low</td>
<td>No</td>
<td>Easy</td>
<td>Slow</td>
</tr>
<tr>
<td>Soft Computing Techniques</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuzzy Logic Controller (FLC) [35-40]</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>Yes</td>
<td>Moderate</td>
<td>Fast</td>
</tr>
<tr>
<td>Artificial Neural Network (ANN) [41-48]</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>Yes</td>
<td>Moderate</td>
<td>Fast</td>
</tr>
<tr>
<td>Optimisation Techniques [49-51]</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>No</td>
<td>Difficult</td>
<td>Fast</td>
</tr>
</tbody>
</table>
Perturb & Observe (P&O) and Incremental Conductance (INC) classical techniques gain better acceptance at practical implementation stage due to achieve moderate performance and lesser complexity in implementation. However, these conventional techniques can be further modified to enhance their limitations lies in convergence speed with slow response time. Apart from that, these techniques lack of satisfactory transient and steady state system response which considered as a negative aspect or challenge on control point of view. Soft computing techniques are taken as another powerful alternative as compared to conventional approaches due to better edge over on robust operation, fast tracking, nonlinear system tolerant and offline training point of view. Although to achieve the best for these techniques it need to emphasize on several aspects such as controller configuration, required measurement signals, training algorithms and implementation complexity. Looking for a better MPPT technique one can either search for a new technique or can give a second thought to upgrade the existing techniques with an intention to reduce their limitations. With a detailed survey by analyzing both advantage and particularly focussing on the associated limitations we planned for a better technique by upgrading the conventional and soft computing techniques. So an attempt has been made to design a robust MPPT controller by combining the optimal capabilities of the individual conventional and soft computing MPPT techniques.

1.3.2 On Load Sharing Control

Droop concept for power sharing control refers to the control strategies that operate to decide the power generation of individual DG corresponding to a particular load demand without any inter-unit communications. However, the factors like complexity, high cost and low reliability of a supervisory system are the major reason of wide acceptance of droop concept over communication based power sharing control. Apart from that the expansion of a system without stopping the whole system or in other words replacement of one unit is easier due to plug and play features of the modules particularly in case of droop concept based design. The basic objective of the droop control is composed of two functions such as frequency droop control and output limit control. A summary of conventional droop control methods are presented in Table 1.2 with their potential advantages and limitations.
Table 1.2: Potential advantages and disadvantages of the conventional droop characteristics based control methods.

<table>
<thead>
<tr>
<th>Conventional and variants on droop control</th>
<th>Virtual structure based method</th>
<th>Virtual Impedance droop control (VID) [71],[72],[73]-[74]</th>
<th>Potential advantages</th>
<th>Potential drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real power and Reactive power droop control (PQ Drooping) [52],[53]</td>
<td>Voltage Real power drooping or Frequency Reactive power boosting droop control (VPD/FQR) [54],[55]-[57]</td>
<td>Decoupled active and reactive controls Improved voltage regulation</td>
<td>For highly resistive transmission lines Easy implementation without communication</td>
<td>Affected by the physical parameters Poor voltage-frequency regulation Slow dynamic response Poor harmonic sharing</td>
</tr>
<tr>
<td>Complex line impedance [58]-[64]</td>
<td>Angle droop control [65]-[67]</td>
<td>Constant frequency regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Droop control with constant power band [68]-[70]</td>
<td>Virtual Impedance droop control (VID) [71],[72],[73]-[74]</td>
<td>Not affected by the physical parameters Improved performance of power sharing and system stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual structure based method</td>
<td>Enhanced virtual impedance control [75]</td>
<td>Can handle linear and nonlinear loads power sharing Mitigates the PCC harmonic voltage</td>
<td>Requires the low-bandwidth communication The physical parameters should be known in advance</td>
<td></td>
</tr>
<tr>
<td>Virtual frame transformation method [76],[77]-[80]</td>
<td>Virtual frame transformation method [76],[77]-[80]</td>
<td>Decoupled active and reactive power controls</td>
<td>Hard to exactly ensure the same transformation angle for all DGs The physical parameters should be known in advance</td>
<td></td>
</tr>
<tr>
<td>Constructed and Compensated based method</td>
<td>Adaptive voltage droop control [81]</td>
<td>Improved voltage regulation Improved system stability and power sharing under heavy load condition</td>
<td>The physical parameters should be known in advance</td>
<td></td>
</tr>
<tr>
<td>Synchronized reactive power compensation [82]-[83]</td>
<td></td>
<td></td>
<td>Requires the low bandwidth synchronized communication</td>
<td></td>
</tr>
</tbody>
</table>
The review as described in Table 1.2 reflects several drawbacks of the conventional droop characteristics such as load dependency of frequency and voltage deviations, not taking into account the harmonic sharing of non-linear loads, adverse effect of different and unknown line impedances on power sharing performance, fluctuant and changeable output power of DG’s itself. In the recent past, numerous attempts have been made to overcome these drawbacks and minimize the circulating current under all situations by several proposed methods. These methods can be categorized based on their approach such as: 1) conventional and variants on droop control; 2) virtual structure-based method; 3) constructed and compensated-based method; and 4) hybrid droop/signal-injection-based methods [93]. However, the performance of the well accepted and practically implemented conventional droop methods like P-Q drooping, VPD/FQB and VID droop control can be enhanced with modification reducing their limitations.

### 1.4 Motivation

In the recent past fuzzy logic controller (FLC) has been implemented in many areas and is proven to be the most efficient soft computing technique because of the following advantages: a) computationally simple, b) ability to handle system nonlinearity and uncertainty, c) possess excellent convergence speed, d) capability to control any single or multiple input and output systems, and e) easy representation of the knowledge about the control action [94-95]. Nevertheless irrespective of all the above cited advantages of FLC the major limitations includes: a) the designing of the FLC for obtaining an optimum result; b) dependency of performance on expert’s knowledge and experience; c) careful selection of
parameters, definition of membership functions and fuzzy rules; and d) large computational burden. However the optimal capabilities of FLC particularly with respect to microgrid control are not yet exploited much. This motivates us to further investigate in the areas of MPPT control and power sharing control in microgrid environment.

Many authors have also suggested the applications of the evolutionary techniques in various areas of power control. The optimization techniques possess many advantages such as: 1) conceptual simplicity; 2) broad applicability; 3) do not impose nonlinear constraints; 4) non-involvement of non-stationary condition; 5) do not incorporate noisy observations or random processing; 6) possess potential to use knowledge and hybridize with other methods; 7) increased potential to more complex problems; 8) robust to dynamic changes; 9) capability for self-optimization; and 10) ability to solve problems that have no known solutions [96]. These computational techniques also have its own demerits of leading the system to jerk and instability, and system behavior being discrete in nature. For any parameter to tune, the conventional approach generally needs appropriate mathematical modeling of the system and operationally having high complexity in computation due to integro-differential equations involved. Apart from that, the probability to be trapped at local minima is much higher than the evolutionary based optimization techniques. However the capabilities of the evolutionary techniques to compute optimal parameter values for complex systems compared to conventional approach is much higher. This motivates us to further explore this approach for MPPT and power sharing control problems in microgrid environment.

The combination of two or more techniques taking care of their individual limitations forming a hybrid method can enhance the performance of any system. Even if the FLC is a very powerful technique by itself still the performance depends on the choosing of the appropriate system parameter values or function. So the performance can be enhanced by a hybrid approach by computing the necessary fuzzy parameters by rightly applying the evolutionary optimization techniques. This motivates us to adopt the combined approach for most of the applications in this study.

Among many possible intermittent sources, fuel cell is gaining its attraction to PV based DG system due to the following reasons: 1) high integrating efficiency with RES; 2) high reliability and low maintenance cost; 3) fast response; and 4) fuel cell can be installed near to the load with reduced noise and emission [97]. Due to the above reason a hybrid
operation of fuel cell with PV is studied with an objective to smoothing the PV output power with proper MPPT and power sharing control.

The reasons of integration of storage devices to PV based microgrid fulfil to accompany the important tasks such as: 1) smoothing power fluctuation; 2) shift peak generation period; and 3) protection during outage when installed along with large PV generation. As the primary objective of the study is to find out a solution of proper power control, so the need of storage devices cannot be ignored on operational point of view. Looking to the extensive use in recent times and compatible operational characteristics to PV array, supercapacitor is taken as energy storage devices in this study.

FACTS devices basically are power electronics based and other static controllers to incorporate for enhancing controllability and increase power transfer capability by control of one or more system parameters. Among shunt connected controllers STATCOM is used as a static var compensator whose capacitive and inductive output current can be controlled independent of the ac system voltage. The use of STATCOM in distribution sector apart from power regulation is also used for power quality control. In technical terms it is generally known as DSTATCOM. In view to the multi-functional capability of DSTATCOM, its impact on PV based microgrid system is further investigated to enhance the power control with proper voltage and frequency regulation.

Power quality issues cannot be side-lined whenever we design any controller in distribution sector focussing on power control. It is due to the reason that not only the DG’s but also the energy storage and FACTS devices are integrated to the microgrid system through power electronic based inverters along with non-linear loads (harmonic loads). So this motivates to analyze and access the power quality issues to make sure of implementation feasibility of the proposed control approach in this study. As the major focus of this study is to investigate further on the enhancement of power control the study of power quality is restricted only to assessment level to verify the indices to be within the IEEE standard limits.

### 1.5 Objectives of the Research Work

**General Objectives**

In general, the objective of this work can be stated as planned initially to control and regulate power in the distributed microgrid system by finding valuable solutions through innovative control strategies. Fig.1.2 illustrates the schematic skeleton of the major objectives
of this research work. In a broader view this goal is accomplished by achieving several specific objectives as follows.

**Specific Objectives**

The specific objectives of the study are:

1) It is very much needed to take a test model close to the real time distribution system for justifying the efficiency of proposed control strategy as a solution to the main objective. So as a first step the initial objective of this work is to formulate an appropriate mathematical design and modelling the system for PV and SOFC along with other auxiliary equipments for simulation.

2) To accomplish the main idea to regulate power, it is thought to formulate innovative techniques for optimal MPPT control of PV system under islanded and grid connected mode of operation along with different possible environmental conditions.

3) To execute the study for a microgrid integrated with multi microsources, it is necessary to study the operational characteristics and to frame appropriate controller of SOFC. So a part of the research work has been done with an objective to suggest an optimal controller for SOFC.

4) To implement the idea of proper power sharing as a second approach to enhance the overall power control, the next step proceeds with an objective to find out innovative techniques for optimal power sharing between PV and SOFC.

5) Integration of supercapacitor and DSTATCOM in microgrid is planned for further study of the research work to improve the power control with better voltage and frequency profile as a support of reactive power compensation source.

![Fig.1.2: Major objectives of the research work](image)
1.6 Major Contributions

The following are the contributions made in the process of achieving the objectives of the research work:

On preliminary work

- A detailed literature survey on the power control based on MPPT and load sharing techniques.
- An extensive presentation of modelling of PV and SOFC for simulation of test system

On MPPT Control

- Implementation of Dynamic PI (DPI) Controller and Seeker based Fuzzy technique for enhancement of dynamic characteristics, power quality and power tracking

On Power Sharing Control

- Implementation of Dynamic Fuzzy Logic Controller (DFLC) technique for enhancement of the effectiveness of the conventional VPD/FQB drooping approach.
- Implementation of Seeker Optimized based Dynamic PI (SOA-DPI) technique for enhancement of the conventional VPD/FQB drooping approach.
- Implementation of DPI controlled modified perturb and observe (MP&O) and Seeker Optimized Dynamic PI MP&O (SOA-DPI) technique to assure the true and oscillation free MPP to avail the maximum energy cost efficiency and better power sharing.
- Implementation of DPI controlled Virtual Impedance Drooping and Seeker Optimized Dynamic PI controller to establish the communication less power sharing between two micro sources such that the energy cost efficiency remains at its peak.

On Reactive Power Compensation and Voltage Profile Improvement

- Implementation of Seeker Optimized based Dynamic PI controlled Virtual Impedance Drooping with supercapacitor as energy storage device and DSTACOM as FACTS device for compensation of reactive power and voltage profile improvement.
1.7 Chapterization

This thesis is organised in 7 chapters. The following Fig 1.3 gives a brief description of the broad contains of each of the chapter of the thesis.

Fig.1.3: Topology of the thesis outline

Chapter-1 presents an introduction to the research work on power control in DG’s integrated microgrid system. In order to properly define the aim of the work corresponding background study are been described. With a view to access similar techniques being implemented a thorough literature reviews are being done. The motivation and the major contributions of the research work are clearly provided.

Chapter-2 provides the mathematical design approach of the microsources, PV and SOFC considered for the simulation of the entire research work.

Chapter-3 deals with the conventional MPPT control techniques for islanded and grid connected PV distribution system. In addition, it also describes the proposed MPPT control techniques in various conditions like varying voltage, load, irradiance and partial shading.

Chapter-4 presents the design of Fuzzy and HBCC based Adaptive PI control strategy of an islanded Microgrid system with Solid-Oxide Fuel Cell (SOFC) under very often occurred practical operating conditions like change of linear and non-linear load, and voltage variation.

Chapter-5 describes the conventional power sharing methods for low and high voltage islanded microgrids. Further an extensive study of the dynamic stability of the test system
and performance of the proposed approach subjected to variations in load, real, and reactive power enhancements of the conventional methods by the proposed techniques are also presented considering the two DG’s as DC sources and also replacing it with PV and SOFC.

Chapter-6 presents the effect of integration of energy storage system (ESS), i.e. a supercapacitor with high power density during fault condition to equilibrium any transient power mismatch. In addition, it also describes the effect of integration of flexible AC transmission systems (FACTS) devices, i.e. a DSTATCOM during any fault condition to stabilize the grid voltage rapidly during sub-transient period. The proposed techniques are presented and contrasted with the conventional techniques under various faulted conditions.

Chapter-7 summarizes the thesis concluding remarks, discussions on major findings, and also presents the scope of future work.