Power Quality Improvement in Micro grids using Predictive Technique Based Static Compensator

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Abstract

Power quality may be caused when maximum AC loads consumes reactive power. Distribution STATCOM is a custom power device (CPD) which is used to control the flow of reactive power in the Microgrid. Compensation of reactive power and the other power quality issues are being analyzed with the help of Model Predictive control (MPC) algorithm. The detailed modeling and simulations of MPC with DSTATCOM are presented and implemented along with necessary equations in the MATLAB simulink using the simpower systems tool boxes.

Keywords: Power Quality, Reactive power control, Microgrid, predictive control, DSTATCOM

I. INTRODUCTION

In the early days of power transmission problems like voltage deviation during the load changes and power transfer limitation were observed due to reactive power imbalances. The fast developments of sustainable energy resources and the distributed generation units are integrated to the distribution grid which helps to reduce the power transfer limitation. This method is used in the development of Microgrid. Microgrid is an electrical system consists of distributed energy resources, energy storage units and loads which are situated at a long distances from the Grid. This small grid is electrically connected to the main grid by means of a static switch and controlled results into two different operation called grid connected and islanded mode of operation.

The FACTS devices offer fast and reliable control over the parameters, ie. Voltage, line impedance and phase angle between the sending end voltage and receiving end voltage. On the other hand the custom power device is for low voltage distribution and improving the poor quality and reliability of the supply affecting sensitive loads. FACTS devices are similar to CPD. Mostly known custom power devices are DSTATCOM, UPQC, DVR among them DSTATCOM is very well known and can provide cost effective solution for the compensation of reactive and unbalance loading in the Microgrid. By the usage of CPD in the Microgrid system, we can improve the energy reserves and also it helps in improving the power quality of the system. The distributed generation units are used to store and generate energy from small renewable sources. Among the generation units only solar and wind generation are mostly used in Microgrid. The dynamic performance is analyzed and verified through simulations.

The performance of the DSTATCOM depends on the control algorithm ie. the extraction of current components. For this purpose there are many control schemes which are reported in the literature and some are instantaneous reactive power theory, instantaneous compensation, synchronous reference frame theory, computation based on per phase basis, and the scheme based on neural network. Among the control schemes instantaneous reactive power theory and synchronous reference frame theory are mostly used in the control of the Microgrid. This paper focus on the power quality issues that arise in the distributed system which also cause in the Microgrid. The dynamic performance is analyzed and verified through simulations.

It is a custom power device which is gaining a fast publicity during these days due to its exceptional features like it provides fast response, suitable for dynamic load response or voltage regulation and the automation needs, both leading and lagging VARs can be provided. The causes of power quality problems in Microgrid are generally complex and difficult to detect. Technically speaking the ideal AC line supply by the utility system should be pure sine wave of fundamental frequency (50/60Hz). Different power quality problems, their characterization methods and the possible causes are discussed and which are responsible for the lack of quality power which affects the loads in a Microgrid. We can therefore conclude that the lack of quality power can cause loss of production, damage to the equipment or appliances or can even be dangerous to human health inside a Microgrid. This paper demonstrates that the power electronic based power conditioning using CPD like DSTATCOM can be effectively utilized to improve the quality of power supplied to the customers.

In this work, the effect of DSTATCOM in a Model predictive controller based Microgrid system is studied under MATLAB-SIMULINK power system tool bar. The variations in both real and reactive power exchange with DSTATCOM have been studied.

II. DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator similar to many aspects in DVR, which is used for the correction in bus voltages. Connection (shunt) to the distribution network via a standard
power distribution transformer. It is capable of generating variable inductive & capacitive shunt compensation. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading & lagging reactive current compensation to reduce the amount of voltage fluctuations.

Fig. 2.1: Block diagram of DTSATCOM circuit

The major components of a DSTATCOM are shown in fig.2.1. It consist of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, a PWM control strategy. In this DSTATCOM implementation, a voltage – source inverter converts a dc voltage into a three phase ac voltage that is synchronized with, and connected to the ac line through a small tie reactor and capacitor (ac filter).

A. DSTATCOM components: DSTATCOM involves mainly three parts

1) IGBT or GTO based dc to ac inverters:
   These inverters are used, which create an output voltage wave that’s controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required.

2) L-C filters:
   The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter.

3) Control Block:
   Control block is used which switch pure wave DSTATCOM modules as required. They can control external devices such as mechanically switched capacitor banks too. These control blocks are designed based on the Model predictive control (MPC) technique. It automatically generates the optimum reference currents and feedback to the inverter as pulses.

B. Principle of DSATCOM for Voltage regulation.

1) Voltage regulation without compensator.
   Voltage E and V mean source voltage and PCC voltage respectively. Without a voltage compensator, the PCC voltage drop caused by the load current, I_L, is as shown in figure 2.2.b as ∆V.

   \[ I_S = I_L + I_R \]

   where I_R is the compensating current.

Fig. 2.2: a. Equivalent circuit of load and supply system
Fig. 2.2 represents the equivalent circuits of load, uncompensated line and compensated line.
\[ \Delta V = E - V = Z S I L \]
\[ S = VI \]

From the above equation
\[ I_L = \left( \frac{P_L - j Q_L}{V} \right) \]

So that
\[ \Delta V = \left( R_S + j X_S \right) \left( \frac{P_L - j Q_L}{V} \right) \]
\[ = \left( R_S P_L - X_S Q_L \right) / V + j \left( \frac{X_S P_L + R_S Q_L}{V} \right) \]

The voltage change has a component \( \Delta V_R \) in phase with \( V \) and a component \( \Delta V_x \) in quadrature with \( V \), which are illustrated in Fig 2.2. b. It is clear that both magnitude and phase of \( V \), relative to the supply voltage \( E \), are the functions magnitude and the phase of the load current, namely voltage drop depends on the both real and reactive power of the load.

**C. Voltage regulation using DSTATCOM**

Fig 2.2.c shows the vector diagram with voltage compensation. By adding a compensator in parallel with the load. It is possible to make \( |E| = |V| \) by controlling the current of the compensator.

\[ I_s = I_L + I_R \]

Where \( I_R \) is compensator current.

**D. Basic Operating Principle**

DSTATCOM can generate and absorb reactive similar to that of synchronous machine and it can also exchange real power if provided with an external device DC source.

1) Exchange of reactive power: If the output voltage of the voltage source converter is greater than the system voltage then the DSTATCOM will act as capacitor and generate reactive power.

2) Exchange of real power: As the switching devices are not loss less there is a need for the DC capacitor to provide the required real power to the switches. Hence there is need for real power exchange with an AC system to make capacitor voltage constant in case of direct voltage control.

Hence the exchange of real and reactive power of the voltage source converter with AC system is the major required phenomenon for the regulation in the Microgrid. For reactive power compensation, DSTATCOM provides reactive power as needed by the load and therefore the source current remains at unity power factor in both grid connected mode and Islanded...
mode. Reactive power compensation is provided by the controller by controlling the injected currents with the reference currents to the point of common coupling.

III. SYSTEM DESCRIPTION

The proposed Microgrid consists of a solar module, power from the wind and a Micro turbine which is connected to the grid via a static switch to the loads. A battery is used as a backup unit to compensate the shortage of power generated by the renewable resources. Storage battery is used to provide peak shaving during the grid connected operation and it supplements power during the islanded operation and also to maintain the stability of the network. A typical Microgrid is shown in Figure 3.1. DSTATCOM is employed at the at the distribution level of the Microgrid for the power factor improvement and the voltage regulation. Additionally a DSTATCOM can also behave as a shunt filter to eliminate unbalance or distortions in the source current in the both modes of operation. It is a multifunctional device and the main objective of the control method should be to make it flexible and easy to implement in addition to exploiting its functionality to the maximum.

**A. Model Predictive Controller based DSTATCOM**

The control algorithm used in the DSTATCOM modeling is Predictive control technique (MPC). The compensation of reactive power and harmonics is also done by this method. Each Distributed resources are modeled with the Predictive algorithm separately and added to the point of common coupling. Only the first step of the control strategy is implemented, then the model state is sampled again and new calculations are repeated starting from the new current state, yielding new control & predicted path. MPC starts adjusting the control signal head of the reference changes.

MPC controller is shown in figure 3.2. The reference currents are produced by the MPC by the help of three reference signal constants converted to alpha-beta version and is given to the Predictive control block from the Simulink tool box. Actual currents are also sensed and given to the controller block. Controlled output signals will be fed to the PCC from each modeled Distributed resources.
IV. RESULTS & DISCUSSIONS

The Simulink diagram of the proposed Predictive control based DSTACOM is shown in the figure 4.1.

The test model contains three Distributed energy resources which are modeled with the Predictive controller and the power ratings of the solar and wind models with a varying output of 5kW and reactive power of 10kW varying with respect to time. Three loads are connected to the PCC with two light loads of 25 kW each and a nonlinear load of 18 kW with 8.5KVAR and 12.3 KVAR respectively. The grid rating is 2500 x10^6 VA and 60 Hz frequency.

The test micro grid was simulated in two different modes of operation.

1) Grid Connected mode:
The simulation sequence was as follows. Load1 was decreased from 25 kW and 18 kW to 20kW and 10 kW at 1.2 s to investigate power sharing in terms of load variation during grid-connected operation. At 2.0 s, the static switch was opened so that the Microgrid was islanded from the grid. Output Active & Reactive power at the Grid and load side is shown in the simulation graphs from the figure 4.2 & 4.3.

Fig. 4.1: Grid connected mode with DSTATCOM

Fig. 4.2: Grid Side Active & Reactive power
From the above shown graphs, when all the loads are connected to the grid the active power becomes 80kW and reactive power becomes zero due to the compensation in grid side.

2) Islanded Mode:
The static switch was opened and the grid will be disconnected from the AC bus. Load is being varied to appropriate values. The IGBT inverters which are modeled in each Distributed sources with the MPC will operate in Islanded mode. If there is any decrease in the DG output to load, the controller compensates the DS output. Figure 4.4 shows the Microgrid operation in Isolated mode of operation.

![Graph showing Active & Reactive power](image)

**Fig. 4.3: Load side Active & Reactive power**

![Diagram of Islanded Mode with DSTATCOM](image)

**Fig. 4.4: Islanded Mode with DSTATCOM**
In the islanded mode of operation, when all the linear **loads** are connected to Microgrid, load power is compensated by the MPC based DSTCOM at the PCC. From the figure 4.5.a. It’s clear that the DSTATCOM compensates the active and reactive power in the Islanded mode up to 0.2s of the Microgrid and loads. Its negative value is of \(2.5 \times 10^4\) VAr of reactive and 500 W of active power. Figure 4.5 shows the load side Active and reactive power in the Isolated mode of operation.

Voltage variations were seen in this mode of operation when non-linear load is connected. This is shown in the figure 4.5.b.
These variations are due to the presence of these non-linear loads. Due to the presence of second order harmonics with Non-linear load in the isolated mode of operation all the DG’s are connected to a single modelled structure as shown in Figure 4.6 to improve the system stability when the Grid is disconnected.

![Incorporated view of DG’s](image1)

Fig. 4.6: Incorporated view of DG’s

All the modeled DG’s are connected to a single MPC controller and it has been connected to the point of common coupling (PCC) with the DSTATCOM. The output of the current view is shown in the figure 4.7. It is clear that Reactive power is being compensated in the islanded mode of operation completely. Negative reactive power is caused by capacitive loads that include lighting ballasts, variable speed drives for motors, computer equipment, and inverters.

![Load active and Reactive power.](image2)

Fig.4.7: Load active and Reactive power.

The suggested model after the incorporation of the above renewable energy resources are given below in the fig.4.8. The model is done from the existing model of Microgrid which is applicable to isolated mode of operation due to the presence of non-linear loads. DSTATCOM is also modeled with Model Predictive technique and was created a sub system.
Battery (SOFC) was verified with the suggested incorporated model. All the blocks were modeled with the help of MPC control technique. Some filters were used to get a satisfactory output in connection of battery to the model. The Model is shown in the fig.4.8.

V. CONCLUSION

Custom power devices (CPD) can be used, at a reasonable cost to provide high power quality and improved service of the Microgrid in both Grids connected and isolated modes. Detailed modeling of the DSTATCOM is presented and the results are discussed with and without compensator. This paper presents the detailed modeling of one of the Custom power devices modeled with the help of Predictive controller. MPC algorithms are helpful in the simulation of non-linear loads. The control scheme maintains the power balance at the PCC to regulate the voltages. In both aspects the non-linear load injects harmonics to the Microgrid, but it is cleared and compensated with the help of DSTATCOM. It is concluded that a DSTATCOM though is similar to a STATCOM at transmission level; its control scheme should be such that in addition to complete reactive power compensation, power factor correction and voltage regulation the harmonics are also checked and for improving power quality of the Microgrid.

APPENDIX

<table>
<thead>
<tr>
<th>DC VOLTAGE</th>
<th>400V</th>
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<tr>
<td>SWITCH FREQUENCY</td>
<td>16Hz</td>
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</table>
GRID VOLTAGE | 400kV, 2500MVA
VOLTAGE IN ISLAND | 390kV, 60Hz
LIGHT LOAD1 | 25kW, 8.5kVar
LIGHT LOAD2 | 25kW, 10kVar
NONLINEAR LOAD | 18kW, 12.3kVar
X/R RATIO | 10
Vdc | 350 V (Vary)

REFERENCES