Configurations of AC and DC-type Quality Control Center for a New Distribution System FRIENDS

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Abstract

Unbundled power quality service is paid much attention under the circumstances of deregulation and diversification of needs of customers for quality and price of electric power. Moreover, distributed generators (DGs) such as photovoltaic generations and wind turbines will be introduced to distribution system more and more, and reverse flow of active power has possibility to cause new problems in the distribution system such as voltage rise of distribution line and protection problem.

Flexible, Reliable and Intelligent Electrical eNergy Delivery System, which is called FRIENDS, has been proposed as one of promising distribution system for such requirements, and intensive studies are under way. One of features of the system is introducing Quality Control Center (QCC) into the system for unbundled power quality service and easy installation of DGs. Two types of QCCs for such purposes are proposed, and simulation results are shown in this paper.

keywords: FRIENDS,Quality Control Center,Unbundled Power Quality Supply

1 INTRODUCTION

Power quality issue is becoming more and more important due to wide spread use of computerized and power electronic equipment, which requires high quality power. On the other hand, some loads require lower price power rather than such high quality power. From this point of view, unbundled power quality supply system, which enables us to deliver different power quality levels to loads, will be preferred for the distribution system in near future[1][2]. Moreover, distributed generators such as a photovoltaic generation and wind turbine have been introduced to distribution system and reverse flow of active power has possibility to cause new problems in the distribution system such as voltage rise of distribution line and protection problem.

Under these circumstances, more flexible system is required for the electric power distribution system in near future. FRIENDS, has been proposed as one of promising system for such requirements[2], and intensive studies are under way[3],[4],[5]. One of features of the system is introducing Quality Control Center into the system for unbundled quality power service and flexible operation.

In this paper, two types of QCCs are proposed; AC-type QCC and DC-type QCC. Main characteristics of these QCCs are that power fluctuations from DGs such as wind turbine and photovoltaic generation can be compensated in proposed QCCs and unbundled power quality service is operated. Simulation results about these characteristics are shown here.

2 AC-TYPE AND DC-TYPE QCCS

Considerable researches have been carried out for FRINEDS concept for realization of unbundled power quality services, and various types of QCCs are proposed. Required functions of QCC are summarized as follows.

1. Several qualities of power are supplied to customers.
2. Unbalance and harmonics current from loads are compensated.
3. Power fluctuation from DGs and loads is compensated and reverse power from DGs is absorbed.

2.1 AC-TYPE QCC

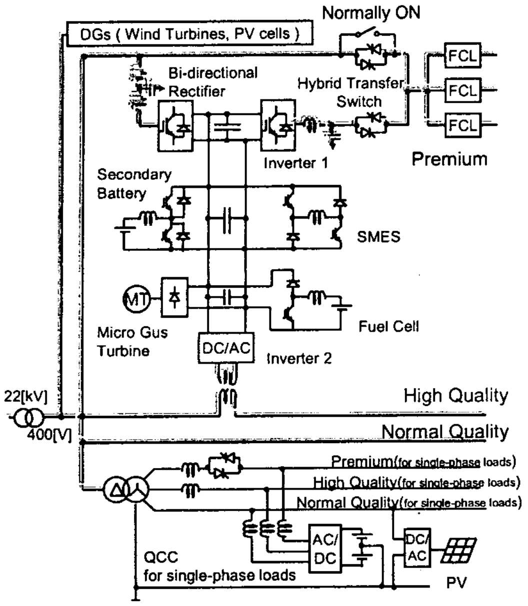
In Fig.1, configuration of AC-type QCC is shown. This system is composed of three AC/DC converters, a hybrid transfer switch, an unbundled power quality supply system using three-phase four-wire ac system, and some DGs.

In the premium line, a hybrid transfer switch is applied to reduce losses caused by semiconductor switching devices in the transfer switch and the inverter[6]. A bi-directional rectifier is installed to connect DGs and DESSs(Dispersed-type Energy Storage System) with AC line, and compensate power fluctuation caused by DGs such as wind turbines. In the high quality line, voltage sags and fluctuations are compensated by the inverter which operates as a DVR(Dynamic Voltage Restorer).

For single-phase loads, unbundled power quality supply system using three-phase four-wire ac system is applied, and three different qualities of power are delivered[7].

2.2 DC-TYPE QCC

Configuration of DC-type QCC is shown in Fig.2. This system has three DC-loop lines[8], that is, the high quality loop, the normal quality loop and the ground loop. Characteristics of this system are described below.



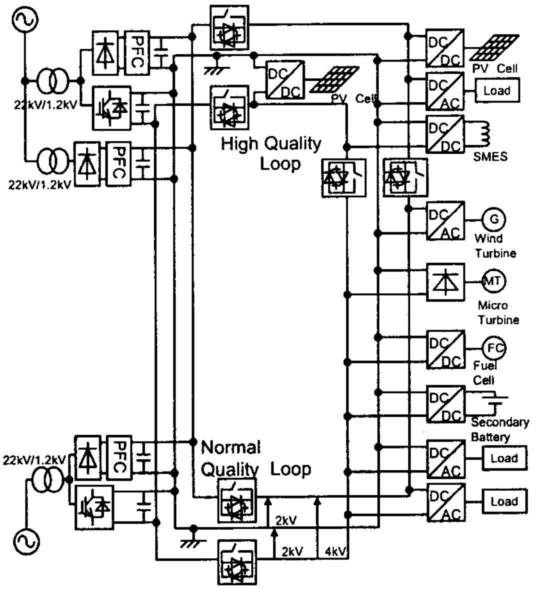


Fig.2: Configuration of DC-type QCC

1. DGs and DESSs which have DC outputs can be installed easily, by using a dc-dc converter which utilizes less switching devices than ac-dc converters.
2. Two kinds of voltage levels can be selected. (For example, 2[kV] and 4[kV] in Fig.2)
3. This system is composed of only three lines to deliver two qualities of power.
4. Losses caused by rectifiers can be reduced, because rectifiers are centralized at the input of QCC.

In the high quality line, interruptions and voltage sags are compensated by DGs such as FC(Fuel Cell) and MT(Micro gas Turbine) which can produce stable power. The bi-directional rectifier and the diode-rectifier with PFC(Power Factor Correction)[9] are installed for compensation of voltage fluctuation in the DC line. In the normal quality line, diode-rectifier and PFC are applied for reduction of costs and losses.

3 CONTROL SYSTEM

In this section, the control system of these proposed QCCs are shown. The control scheme of the bi-directional rectifier for power fluctuation compensation caused by DGs is described for AC-type QCC. The control scheme of the inverter to supply constant power to customers and the bi-directional rectifier to improve power factor on ac side are shown for DC-type QCC.

3.1 CONTROL SCHEME OF AC-TYPE QCC

Control system to compensate power fluctuation is shown in Fig.3. Abc/$\alpha\beta$ conversion and abc/dq conversion are applied to calculate the current reference for the compensation. Required current reference is calculated as follows.

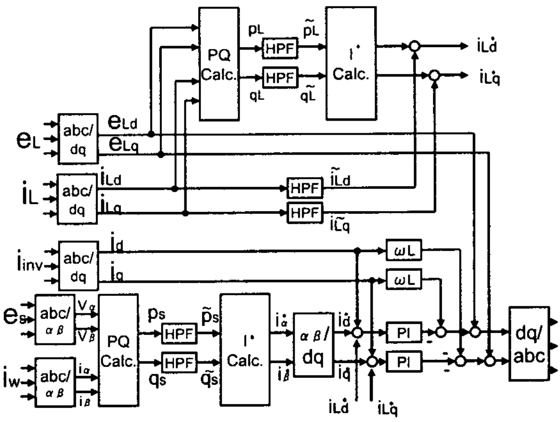


Fig.3: Control System for Power Fluctuation Compensation .

Active and reactive power p, q generated from DG such as wind turbine are calculated by the following equation with e_s for source voltage and i_w for current flowing from DG.

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -1/2 & -1/2 \end{bmatrix} \begin{bmatrix} e_{sa} \\ e_{sb} \\ e_{sc} \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -1/2 & -1/2 \end{bmatrix} \begin{bmatrix} i_{wa} \\ i_{wb} \\ i_{wc} \end{bmatrix}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} i_\alpha & i_\beta \\ -i_\beta & i_\alpha \end{bmatrix} \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ e_\beta & -e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Fluctuation factors of active and reactive power $\tilde{p}$, $\tilde{q}$ are obtained by the output through HPF(High Pass Filter).

Finally, the required current reference is calculated with the following equations.

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{e_\alpha^2 + e_\beta^2} \begin{bmatrix} e_\alpha & e_\beta \\ e_\beta & -e_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix}$$

$$\begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} sin\omega t & -cos\omega t \\ cos\omega t & sin\omega t \end{bmatrix} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -1/2 & -1/2 \end{bmatrix} \begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix}$$

$$= \sqrt{\frac{2}{3}} \begin{bmatrix} sin\omega t & -cos\omega t \\ cos\omega t & sin\omega t \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix}$$

The above mentioned, required current reference to compensate power fluctuation is obtained. Current reference for load fluctuation compensation is also calculated in a similar way.

3.2 CONTROL SCHEME OF DC-TYPE QCC

3.2.1 CONTROL SCHEME OF INVERTER

Even if DC voltage fluctuates, AC output of the inverter must be constant. As the control method of the inverter, pulse width modulation (PWM) is used. The control signal of PWM is the sinusoidal wave which has the amplitude modulation ratio for the peak amplitude. AC voltage can be controlled at a specified value because it changes the amplitude modulation ratio to the fluctuation of DC voltage appropriately.

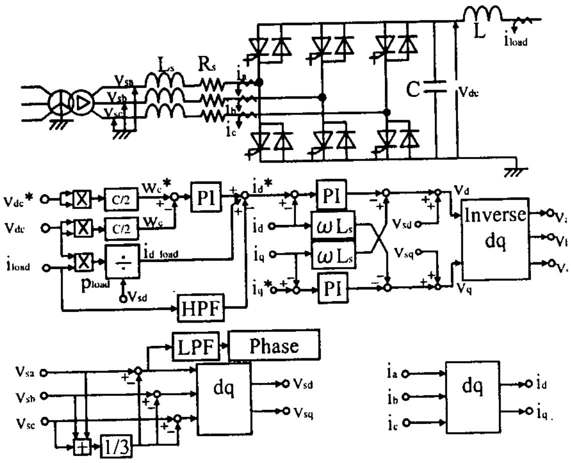


Fig.4: Control System of Bi-directional Rectifier.

On AC output of the inverter, switching harmonic appears because the inverter is switched at low frequency (for example, 900[Hz]) to reduce losses. LC filter is installed to eliminate this harmonic. But the resonance characteristic exists in the LC filter. To restrain this resonance, dumping is added to the control system.

3.2.2 CONTROL SCHEME OF BI-DIRECTIONAL RECTIFIER

In the high quality line, the bi-directional rectifier is installed for compensation of the fluctuation of DC voltage and improvement of power factor. The configuration and the control system of the bi-directional rectifier are shown in Fig.4.

The active current and the reactive current of AC system are controlled independently to improve power factor. The dq transformation is used to realize it. The non-interference current control method is used to control the currents using dq transformation. The active current reference value is controlled for DC voltage to be constant value.

But only in such control, switching harmonic appears because the bi-directional rectifier is switched at low frequency in order to reduce switching losses. The multiple bi-directional rectifier is proposed to eliminate

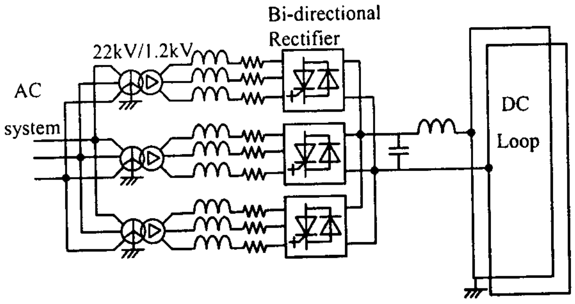


Fig.5: Circuit Configuration of Multiple Bi-directional Rectifier.

4 SIMULATION RESULTS

In this section, simulation results with PSCAD/EMTDC are shown. UPS operation and power fluctuation compensation are shown for AC-type QCC. Simulation results of the inverter control to keep ac output constant and bi-directional rectifier control to improve power factor are shown for DC-type QCC.

4.1 SIMULATION RESULTS OF AC-TYPE QCC

In this simulation, line to line voltage is assumed at 400[V]. This voltage is considered as the distribution voltage in near future.

Secondary battery and fuel cell are installed in Fig.1. Secondary battery is applied to keep DC voltage constant with high response speed, and fuel cell is used to supply constant power to the load in premium line.

4.1.1 UPS OPERATION

Simulation result of UPS operation is shown in Fig.6.

In premium line, active power is delivered from the inverter by switching hybrid transfer switch during interruption. In Fig.6, Interruption occurs from

100[msec] to 150[msec] in primary feeder. This figure represents load voltage is kept at constant value during interruption, and influence of this accident doesn't appear by switching hybrid transfer switch.

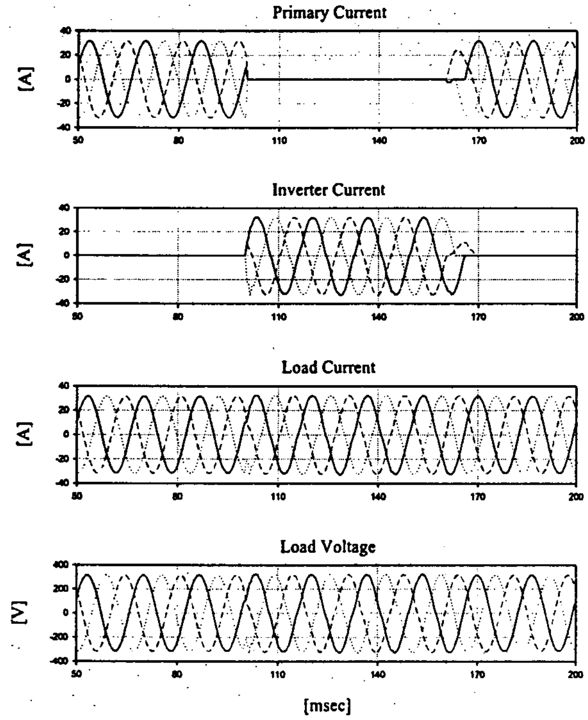


Fig.6: UPS Operation.

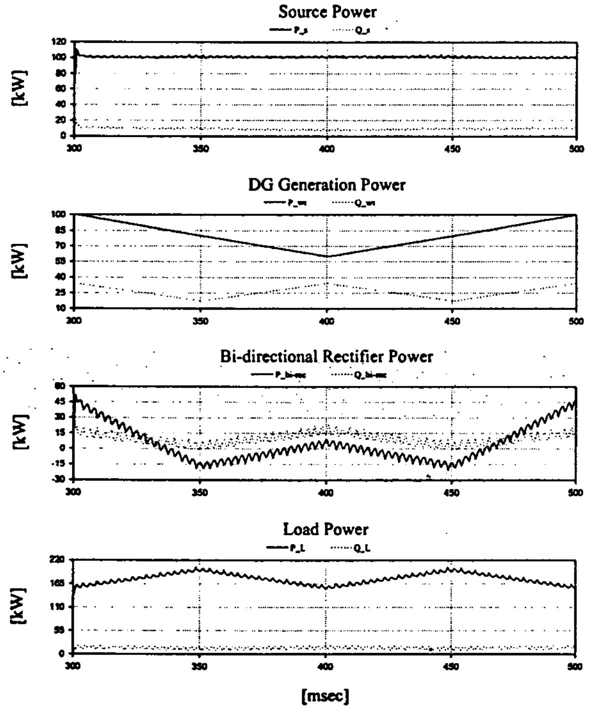


Fig.7: Power Fluctuation Compensation.

4.1.2 POWER FLUCTUATION COMPENSATION

Power fluctuation caused by DSs such as wind turbine must be absorbed in QCC. Fluctuation of active and reactive power is simulated as triangle wave in this simulation.

Simulation result of power fluctuation compensation is shown in Fig.7. The solid and broken line shows instantaneous value of active and reactive power in Fig.7, respectively.

Source power is kept at constant value by the control of bi-directional rectifier although active and reactive power of DG fluctuates. This indicates DGs can be installed easily because primary feeder isn't suffered from DGs.

4.2 SIMULATION RESULT OF DC-TYPE QCC

4.2.1 INVERTER CONTROL

The simulation result using PSCAD/EMTDC software is shown for the inverter in Fig.8. In Fig.8, voltage sag appears after 0.5[s] on source voltage. By this voltage sag, DC voltage fluctuates, too. But inverter voltage (load voltage) is constant because the amplitude modulation ratio (ma) is controlled appropriately against the fluctuation of DC voltage.

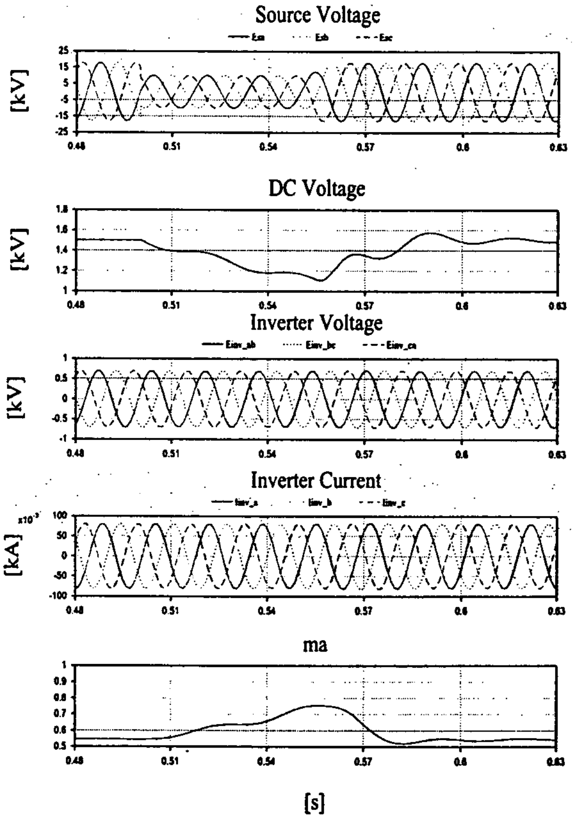


Fig.8: Simulation Result of the Inverter.

4.2.2 BI-DIRECTIONAL RECTIFIER CONTROL

The simulation result is shown for the multiple bi-directional rectifier in Fig.9. In this simulation, two important characteristics are represented. One is DC voltage control. DC voltage is kept at constant by the control of bi-directional rectifier, although load increases rapidly from 0.4[sec] in this simulation. The other is power factor correction. In this figure, source side current is sinusoidal and doesn't include any harmonics by multiple bi-directional rectifiers.

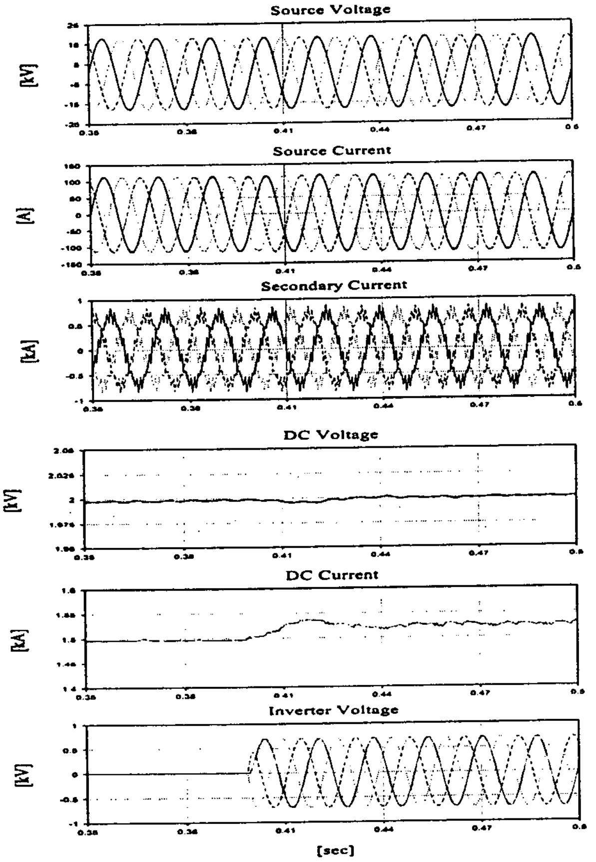


Fig.9: Simulation Result of the Bi-directional Rectifier.

5 CONCLUSION

A new type of QCC for FRIENDS, that is, AC-type and DC-type QCC are proposed.

Characteristics of AC-type QCC are summarized as follows. In premium line, interruptions are compensated by switching hybrid transfer switch as one of characteristics of unbundled power quality service. Moreover, even if power generated by DGs fluctuates, the fluctuation is absorbed by the bi-directional rectifier.

For the DC-type QCC, configurations and simulation results of the inverter and the bi-directional rectifier are shown. In the inverter, even if DC voltage fluctuates, AC output is controlled at a constant value. In the bi-directional rectifier, power factor is kept unity and DC voltage is controlled at a constant value.

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