Electric Power Systems Research 79 (2009) 1553–1560

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Power quality improvement with an extended custom power park

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ARTICLE INFO

Article history:
Received 10 September 2008
Received in revised form 3 June 2009
Accepted 4 June 2009
Available online 4 July 2009

Keywords:
Custom power
Custom power park
Power quality control centre
STS
APF
DVR

ABSTRACT

This paper describes the operation principles of an extended custom power park (CPP). The proposed park is more effective when it is compared to the conventional power parks regarding the yield of improving both current and voltage quality of linear and nonlinear loads using dynamic voltage restorer (DVR), active power filter (APF), static transfer switch (STS) and diesel generator (DG). Moreover, a supervisory power quality control centre is presented to coordinate these custom power (CP) devices by providing pre-specified quality of power. A fast sag/swell detection unit is also presented to improve the system response. The ability of the extended CPP for power quality improvements is further analyzed using PSCAD/EMTDC through a set of simulation tests.

1. Introduction

The control of most of the industrial loads is mainly based on semiconductor devices and microprocessors, which cause such loads to be more sensitive against power system disturbances such as voltage sag, voltage swell, current harmonics, interruption and phase shift. Thus, the prevention of negative effects of the PQ disturbances has gained more interest for the last twenty years [1,2].

CP is a power electronic based solution against PQ disturbances or electromagnetic disturbances. CP devices, namely DVR, APF and STS, are applied in the distribution system of an electric utility with the purpose of protecting an entire plant, feeder, a block of customers or loads [3]. CP devices include an acceptable combination of the following features; no (or rare) power interruptions, magnitude and the duration of voltage reductions within specified limits, magnitude and the duration of over voltages within specified limits and low harmonic currents [4].

The STS is used to transfer the load from the preferred source to an alterative healthy source. The DVR is capable of generating or absorbing independently the controllable real and reactive power at its ac output voltage in series with the distribution feeder in synchronism with the voltages of the distribution system. The APF is one of the CP devices and it is generally shunt connected to the system via a reactance. It can mitigate the harmonic currents generated by nonlinear loads by controlling the compensation current [3,5]. The concept of CPP has been introduced in order to meet customer's needs. CPP concept means the integration of multiple CP devices within the Industrial/Commercial Park that offers the customers a high quality power at the distribution system voltage level [6]. In the literature, there are various studies about a high quality power park concept apart from CPP (unlike CPP). One of the most important studies is the power quality park (PQP) [7]. The classification of customers is the distinguishing feature of PQP and CPP. PQP does not classify their customers while CPP classifies the customers, so that each customer can be offered different tariff rates for required power quality needs.

In this paper, an extended CPP is proposed and various PSCAD/EMTDC simulation studies are performed to validate the performance of the park. The designed park and case studies differ from the conventional power park studies in [8–10] from the following ways:

- Power Quality Control Centre (PQCC) provides a coordination of extended CPP including CP devices and loads, thus resulting in a reliable distribution system and a required qualified power.
- The extra functionality is added by integrating APF to the park and thus an extended CPP is performed.
- A fast fault detection method is presented both for STS and DVR.
- The coordination and interaction between the CP devices are presented comprehensively.

The paper is organized as follows: after this introductory section, general operations of the CP devices in the CPP are described in Section 2. The innovative contributions of the study, the proposed CPP and power quality control centre are presented in Section 3. The

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doi:10.1016/j.epsr.2009.06.001

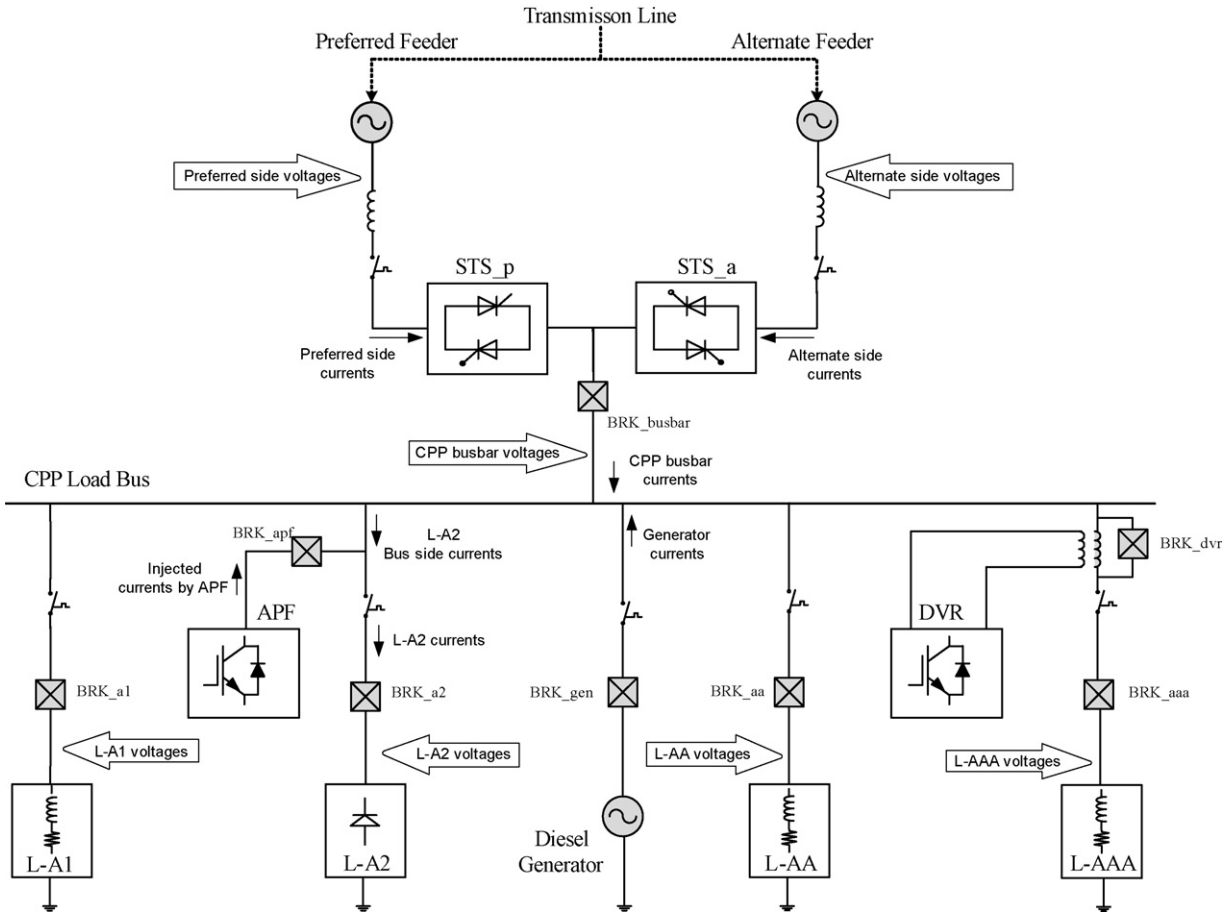

Fig. 1. The single line diagram of the extended CPP.

case studies and discussions showing power quality improvements are presented in Section 4. The main contributions and significant results of the study are summarized in Section 5.

2. The extended custom power park concept

The extended CPP offers a high quality power (grades of A, AA and AAA) to customers and meets the needs of sensitive loads with an Industrial/Commercial business park. Fig. 1 shows the single line diagram of the proposed CPP including STS, DVR, APF, DG, the circuit breakers and loads.

STS protects sensitive loads against voltage sags, swells and interruptions. STS ensures a continuous high quality power supply to sensitive loads by transferring, within a time scale of 4–8 ms, the load from a faulted bus to a healthy one [11]. STS with a make-before-break transfer strategy [12] is used to satisfy the uninterrupted transfer of the power to the critical loads in this study. The detection and transfer logic must function properly for all the possible operating conditions. In this study, the control method used for voltage compensation in [13] is developed for voltage sag/swell detection. By using this approach the detection time can be further improved with the respect to conventional methods using a low pass filter [14,15].

APF mitigates current harmonic disturbances and compensate the reactive power of nonlinear loads. The shunt connected voltage source inverter topology is used in the power circuit. The compensation signal is calculated using the concept of Instantaneous Reactive Power Theory (IRPT) [16], which is based on both load voltage and load current samples.

DVR is connected in series to the distribution circuit by means of a set of single-phase injection transformers and has capable of generating or absorbing the real and reactive power at its ac terminals. To maximize the dynamic performance, a direct feed-forward-type control [2] is applied to the control unit of DVR. With this control, a fast response time (approximately 1 ms) can be achieved to compensate the voltage disturbances. The voltage reference is obtained from the pre-fault line voltage and the compensation signal is calculated using the PQR theory [17].

The coordination of CP devices in the CPP is clearly described in the following sections. A detailed circuit diagram of the CPP system and the circuit parameters are given in Appendix A.

2.1. The profiles of CPP loads and grades of powers

The loads in the park are divided into three categories. Loads L-A1, L-AA and L-AAA are balanced and harmonic-free, while Load L-A2 is a harmonic polluting load. L-AA and L-AAA are the sensitive loads and they require almost an uninterrupted electrical power. L-AAA is the most critical load and cannot tolerate any disturbances. CPP has two incoming feeders designed for an improved grounding and insulation. Thus, all loads benefit from a high quality power supply. L-A1 (and also L-A2), L-AA and L-AAA receive the powers QP-A, QP-AA and QP-AAA, respectively, as shown in Fig. 2.

The grades of the powers are explained below.

2.1.1. Qualified Power-A (QP-A)

QP-A is a harmonic free and sag/swell free power. This is the least qualified power at the park. This grade power requires the use