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Investigation and Analysis of Custom Power Devices

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ABSTRACT

This paper presents a simulation study about the co-ordination and interaction of innovative power electronic devices working in near electrical closeness. In particular, three main power quality devices (PQDs)—an advanced static VAR compensator, a dynamic voltage restorer, and a high-speed transfer switch as well as their combined performance are modeled and studied in detail using ATP-EMTP. The paper discourses prospective problems related to the PQD's combined operation, in addition to harmonization issues. Comparison between simulation results and field dimensions of individual PQD's are also presented.

Keywords—Electromagnetic transient analysis, industrial power systems, power quality, static VAR compensators, vacuum switches, voltage compensation.

I.INTRODUCTION

For the earlier ten years, advanced power electronic devices have been the center of several research studies, installation projects, and development technologies. According to the IEEE P1409 Custom Power Task Force, the number of custom power devices in provision up to May 2000 is as follows [1]:

–Transfer switches: 23 devices

–Static series compensators: seven devices

–Static shunt compensators: 17 devices

By custom power devices, we refer to power electronic static controllers used for power quality enhancement on distribution systems rated 1 through 38 kV. This attention in the usage of power quality devices (PQDs) rises from the need of growing power quality levels to meet the everyday growing sensitivity of customer needs and aspects [2]. Power quality levels, if not attained, can cause costly interruptions and customer obstruction. According to Contingency Planning Research Company's annual study [3], interruption caused by power disturbances results in main financial victims, as shown in Fig. 1.

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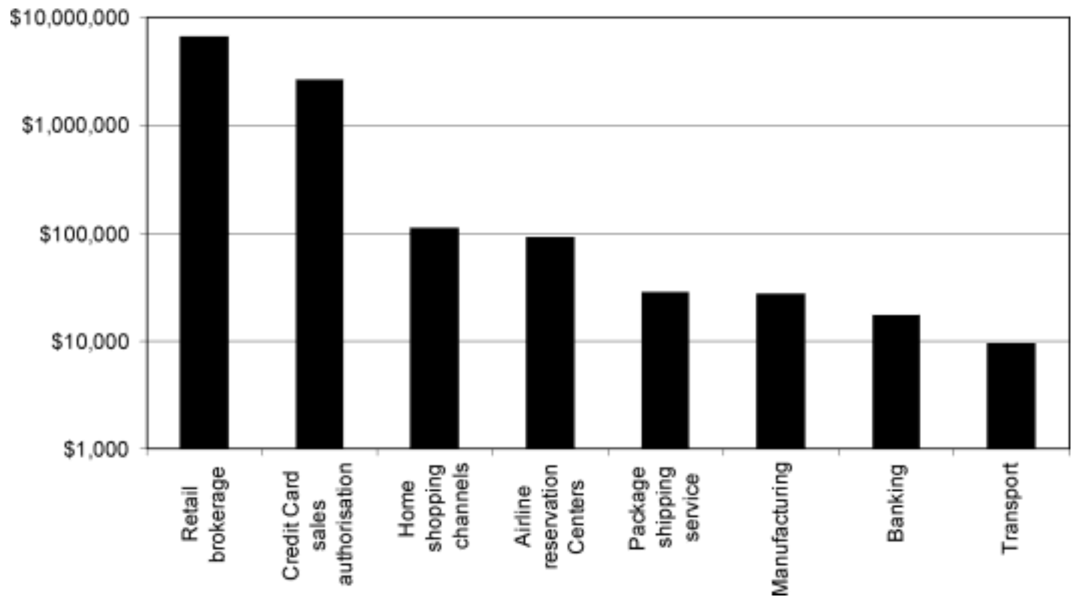

Fig. 1.Average hourly impact of interruption and data loss by business sector [1].

In order to face these new requirements, advanced power electronic devices have ingrained over the last years. Their performance has been revealed at medium distribution levels, and most are available as commercial products [4], [5]. Table I shows the power quality solution matrix that pronounces the emerging PQDs as well as their applications. Even though the well-documented bibliography about individual PQDs, small consideration has been paid to their integrated performance when operating in close electrical closeness. The integration of different devices is an essential component in the success of overall concepts such as custom power parks [1] or quality control centers (concept of FRIENDS) [6]–[8].

TABLE IAPPLICATION FOR PQDS

PQD	Control attributes
D-STATCOM	**Static Shunt Compensator** – Voltage support and stability – VAR compensation (PF correction) – Current harmonic compensation – Load current balancing – Flicker effect compensation
SSC	**Static Series Compensator** – Protection against voltage sags and swells – Voltage balancing – Voltage regulation – Flicker attenuation
STS	**Static Transfer Switch** – Protection against voltage sags and swells
SSB	**Solid-State Breaker** – Fault current interruption – Fault current limitation
SVC	**Static VAR Compensator** – Voltage support and stability – VAR compensation
SSSC	**Static Series/Shunt Compensator** – Protection against voltage sags – Protection against voltage swells – Voltage balancing – Voltage regulation – Flicker attenuation – Interface with DG – Active and reactive power control – VAR compensation – Harmonic compensation – Current balancing

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The objective of the paper is to study the combined operation of different components having coinciding capabilities. In particular, three PQDs (a static series compensator, a transfer switch, and a static VAR compensator) are modeled and in-tegrated into the same system (an industrial park) using the EMTP-ATP software tool. In order to maintain a reliable terminology for these devices when commissioned, the following cross-reference to the IEEE P1409 is included:

–SSC → dynamic voltage restorer (DVR);

–TS → high-speed mechanical transfer switches (HSMTS);

–SVC → advanced static VAR compensator (ASVC).

This terminology will be used throughout the paper. Potential problems related to the PQD's combined operation, in addition to coordination issues, are addressed in the paper. Comparison between simulation results and field measurements of some individual PQDs are also presented.

II.MODELING OF CUSTOM POWER DEVICES PARK

The three dissimilar power quality devices selected to be assimilated into the same system are the following [1], [9]:

–a high speed mechanical transfer switch (HSMTS);

–a 2-MVA DVR downstream of the HSMTS to serve one of the critical customers;

–a 4500-Kvar SVC placed on the alternate feeder for the critical customer. The primary objective is voltage support.

The individual modeling of the power quality mitigation equipment under study is the subject of the next sections.

2.1. Dynamic Voltage Restorer

The Dynamic Voltage Restorer (DVR) is a series-connected device capable of injecting voltages of controllable magnitude and phase through a coupling transformer (Fig. 2).

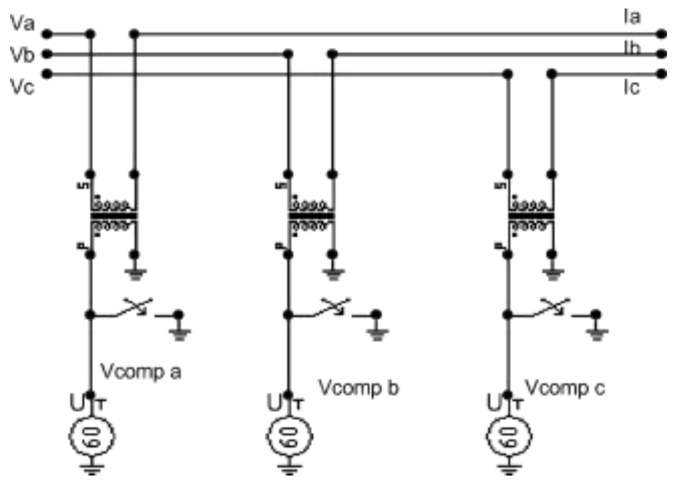

Fig. 2.DVR equivalent model in ATP draw.

The exact modeling of a DVR is fairly complicated; there-fore some oversimplifications should be made. However, the model responses to grid disturbances will be preserved. The DVR's control scheme employed in EMTP-ATP is shown in Fig. 3.

The knowledge behind the DVR's control algorithm is to change the sinusoidal input variable (Va, Vb, Vc) into constant values ($V_d\pm, V\pm, V_o$), reflecting the "instantaneous" magnitude of the positive, negative, and zero sequence components. These values are then compared to the reference values, so the voltage need by the DVR's inverter can be calculated.

The DVR characteristics are as follows:

–power ratings: 2 MVA;

–voltage class: 13 kV;

–functions: voltage sags and voltage swell corrections;

–response time: $^1/_4$ cycles;

–event duration: 10–30 cycles;

–energy storage: capacitors;

–sensitive control: per phase.

The control model of the PLL control loop employed in EMTP-ATP follows the recommendations made by V. Kaura *et al.* [10]. *Fig.* 4 shows the control diagram of the PLL system. As can be concluded from Figs. 2 and 3, the major simplifications considered in the DVR model are as follows.

–The DVR inverter is modeled as three ideal controlled voltage sources.

–No saturation in the control actions is considered.

–No dc chopper or passive filters are taken into account.

The characteristics of the power electronics devices that result in harmonic generation for the DVR were not considered in the model, since it is assumed that the high-frequency harmonic components injected by the inverter are attenuated by the DVR's passive filters. In order to test the validity of the DVR equivalent model, comparison between simulation results and field measurements are made. Fig. 5 shows the performance of both DVR devices (model and real) when the system experiences a SLG fault with 70% retained voltage. The main discrepancies between field measurements and the simulation results is the high-frequency voltage component that the DVR model is able to inject into the circuit. This is due primarily to absence of saturation in the control actions and passive filters, yet the DVR model response to power disturbance is preserved.

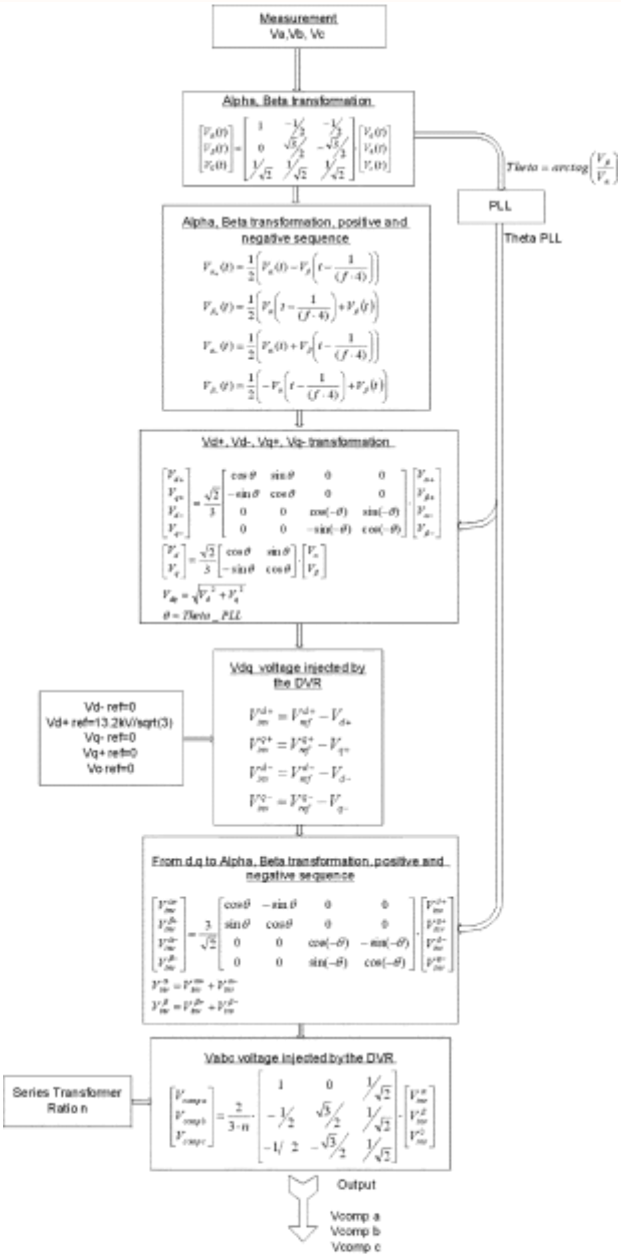

Fig. 3. DVR control scheme implemented in EMTP-ATP.

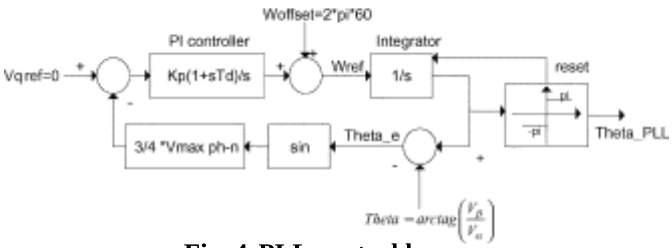

Fig. 4. PLL control loop.

2.2. HSMTS

The HSMTS is a fast-acting vacuum switch that can rapidly transfer sensitive loads from a preferred supply that experiences a disturbance to an alternate supply, such as another utility primary distribution feeder. The HSMTS can accomplish the transfer switching in 25 ms [11], [12], which is fast enough to protect variable-speed drives and PLCs, plus many other critical loads. The high-voltage transfer switch characteristics are as follows:

–device rating: 600 A;

–symmetrical short circuit current rating: 12.5 kA;

–voltage class: 15 kV;

–problem addressed: voltage sags and voltage swell;

–response time: 2 cycles (25 ms);

–sensitive control: Super Switch digital source quality sensing strategy;

–design life: 2500 operations;

–possibility of remote control.

The HSMTS uses a state-of-the art patented control technology, which is able to distinguish in real time between swell, sags, and open sources. However, in order to simply the HSMTS model, a simple sliding RMS magnitude detector algorithm was implemented in EMTP as the sensing technique (Fig. 6).

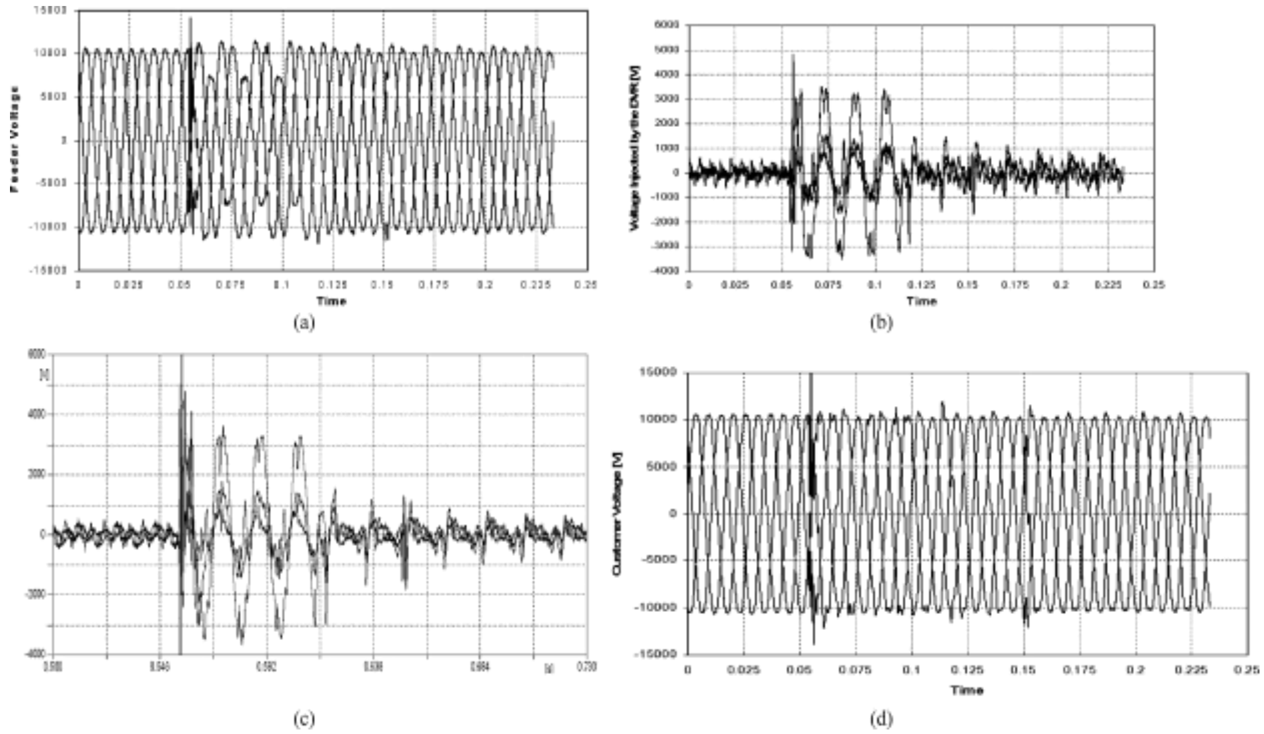

Fig. 5. DVR comparison results. (a) Feeder voltage field measurements (data supplied by S&C). (b) Voltage injected by the DVR. Field measurements. (c) Voltage injected by the DVR. Simulation results. (d) Load voltage. Field measurements (data supplied by S&C).

The vacuum transfer switch, which is one of the most challenging and crucial elements in the system modeling, was modeled as a time-dependent resistor in parallel with an ideal switch (see Fig. 7). Cassie's differential equation was chosen to model the electrical arc due to its simplicity and ability to describe an arc more clearly for higher currents than other models [13]. Fig. 8 shows the HSMTS model performance when the preferred feeder proficiencies a voltage drop below the set up threshold, which, in this case, is 62%. The customer load is modeled as a 3400-HP induction motor in parallel with a 1-MVA passive load.

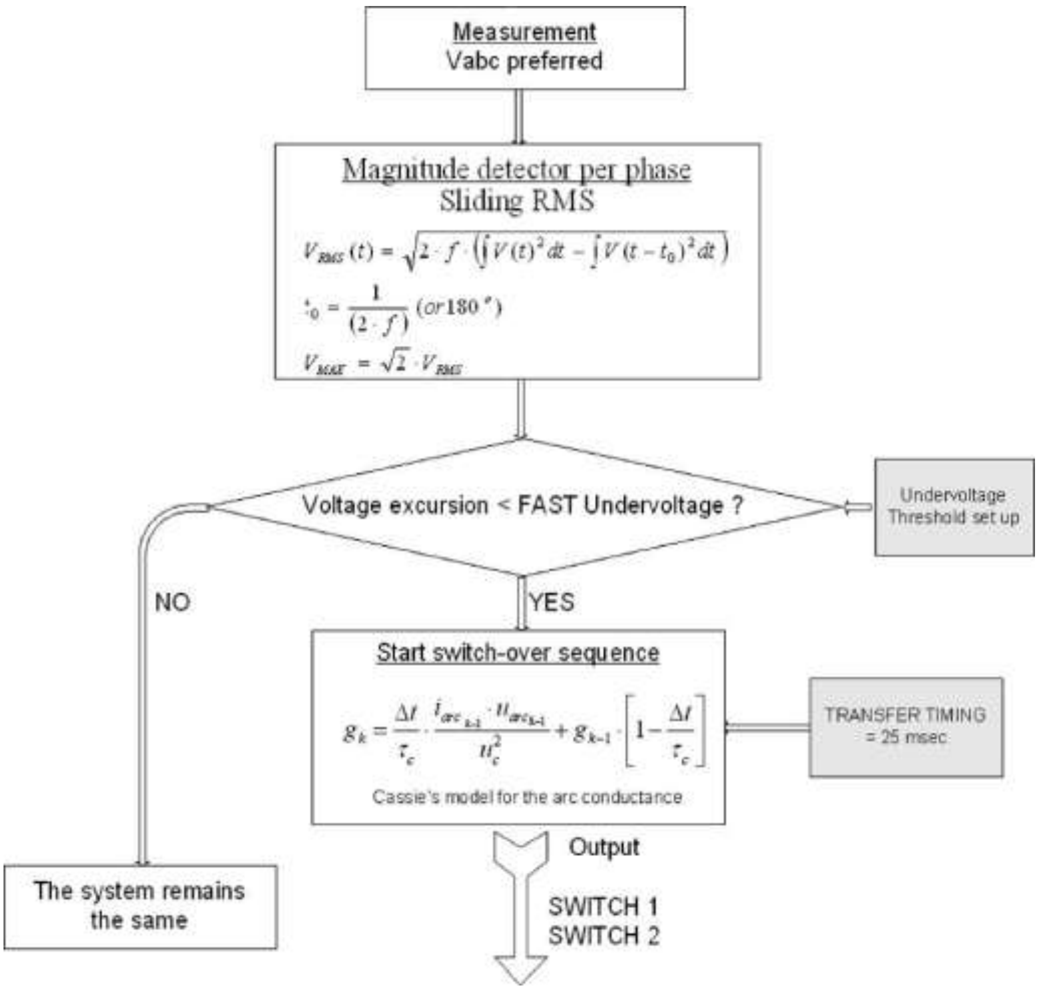

Fig. 6. HSMTS control scheme.

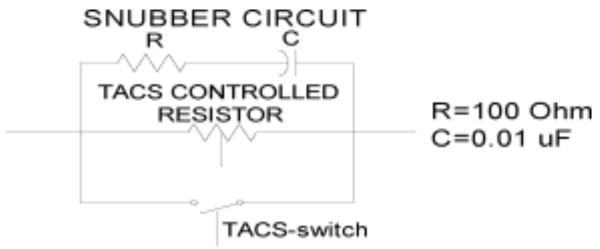

Fig. 7.Vacuum switch topology.

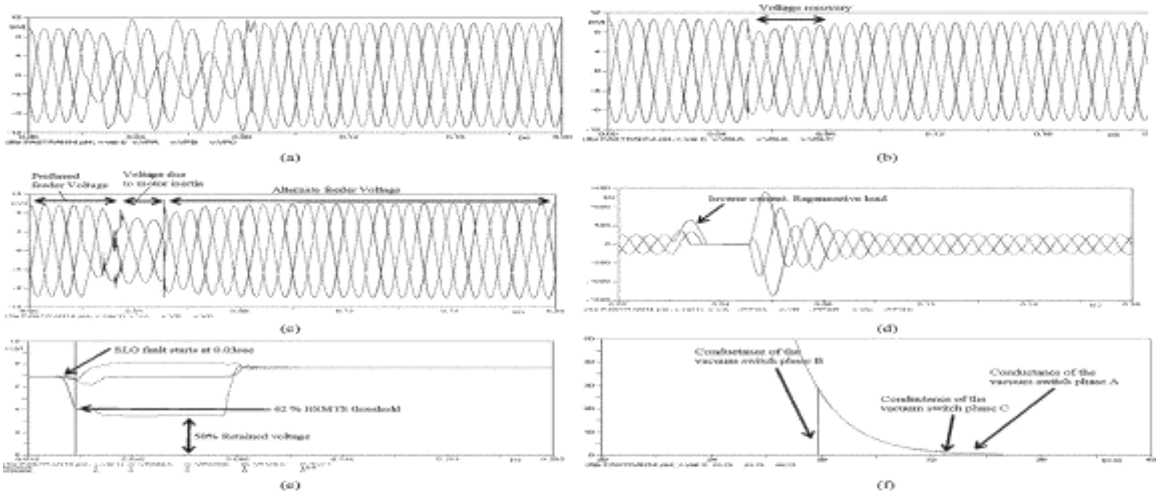

Fig. 8. HSMTS switch over performance. (a) Preferred feeder voltage. Simulation results. (b) Alternate feeder voltage. Simulation results. (c) Load voltage. Simulation results. (d) Load current. Simulation results. (e) Sliding RMS magnitude detector. Simulation results. (f) HSMTS conductance during the opening sequence. Simulation results.

After the sag has been detected, the control system sends an opening signal command to the vacuum breakers. Once the pre ferred feeder is open; the control system will wait a few milliseconds before closing the alternative feeder to avoid possible short circuit currents. During that time, the main customer's passive load will be fed by the energy stored in the motors' inertia.

C. ASVC

An ASVC is a shunt-connected device with thyristor switching of passive reactive components (capacitors and reactors) in distinct steps. They exchange a controlled reactive current with the power system to control electrical parameters of the line at the point of common coupling [1]. ASVC is typically used for voltage control, reactive power compensation, and power factor correction. The ASVC implemented in EMTP-ATP has the following features:

–device rating: 1500 Kvar/phase;

–rated voltage: 15 kV;

–sensing control: independent single phase units;

–capacitor steps: 100, 200, 400, and 800 Kvar;

–maximum resolution: 1 Kvar;

–TCR fills in the gaps between the 100 Kvar;

–control system operates on a cycle-by-cycle basis;

–"switch = in" point of the capacitance of the ASVC occurs at the negative peak of the line voltage.

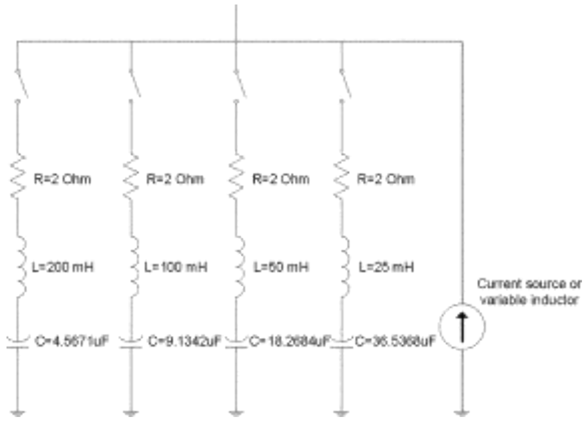

Fig. 9.ASVC equivalent circuit per phase.

From a circuit standpoint, the capacitive reactance is to be modeled as a series of lc circuits tuned at about 168 Hz. (e.g., if we apply 100 Kvar, model L =200 mH and C =4.5 uF; for 200 Kvar, L =100 mH, and C =9.0 uF, etc.). Fig. 9 shows the ASVC equivalent circuit implemented in EMTP. The TCR part of the ASVC is modeled as a single variable inductor (or variable current source), since it is assumed that harmonic currents from the TCR have no significant effect on the voltage or current of the ASVC. The control scheme implemented in EMTP-ATP is shown in Fig. 10. Two main control branches can be identified: the TCR and the TSC.

Fig. 11 shows the ASVC model performance when the feeder, at the ASVC location, experiences a load increase of 400% (the

connected load consists of a 3400-HP induction motor in par-allel with a 1-MVA passive load).

III.CUSTOM POWER PARK

3.1System Description

Fig. 12 represents the custom power park equivalent system modeled in EMTP [14]. The critical customer load is modeled as a 3.2-MVA induction motor in parallel with a 1-MVA passive load.

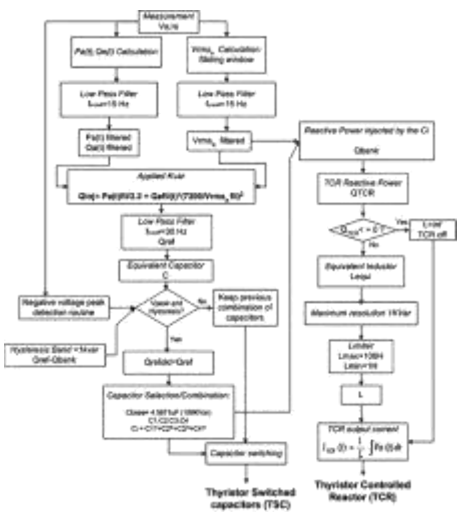

Fig. 10.ASVC control scheme.

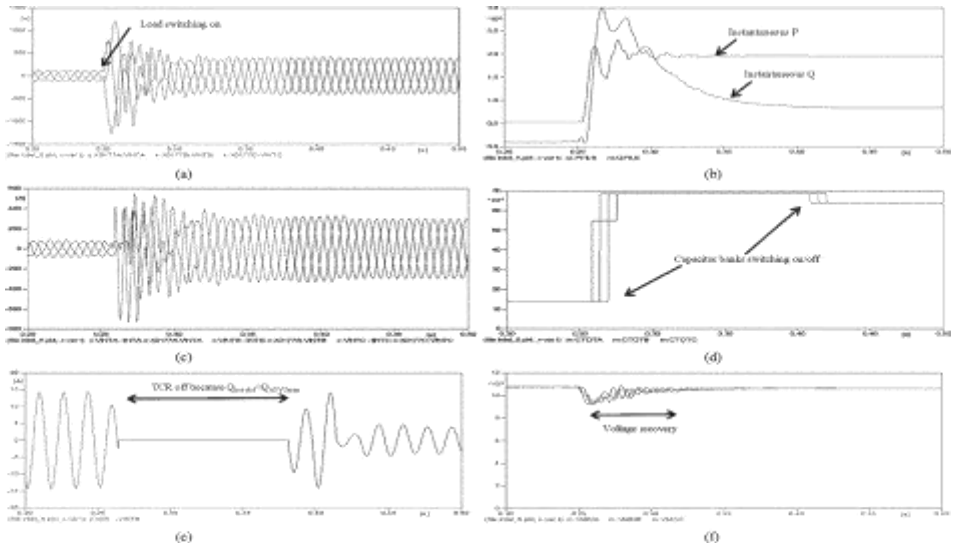

Fig. 11. ASVC model performance. (a) Current delivered by the substation. (b)Instantaneous P and Q for phase B. (c) Current injected by the ASVC. (d) ASVC total capacitance connected. (e) TCR injected current (phase B). (f) Load voltage profile.

3.2. Custom Power Devices Coordination

The HSMTS is placed upstream of the DVR to protect one of the critical customers, while the ASVC is placed on the alternate feeder to the critical customer. The primary purpose is for voltage support. In order to enhance the flexibility of the system with the resulting improvement in power quality, some control functions are centralized. Thus, for example, the DVR and the HSMTS are linked by an interface such that they supplement each other. Taking this coordination improvement into consideration, the transfer thresholds for the HSMTS are set to 62% retained voltage when the DVR is on and 80% retained voltage when DVR is off. The HSMTS will switch over if the DVR runs out of energy due to deep sustained sag. With these premises, the DVR will handle voltage sags down to a retained voltage of 62%, while the HSMTS will transfer to the alternate feeder for voltage sags 62% and below. The DVR is designed to be able to inject up to 40% voltage. Fig. 13 shows the interface implemented in EMTP between the HSMTS and the DVR.

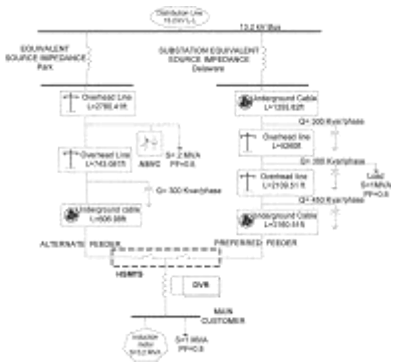

Fig. 12. Custom power park model.

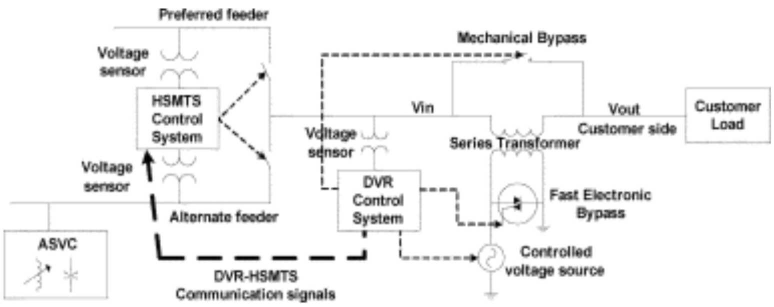

Fig. 13. DVR-HSMTS communication interface.

3.3. System Performance

The following simulation [Fig. 14(a)–(h)] results show the performance of the custom power park when a voltage sag below 62% is presented in the preferred feeder. This type of voltage sag has a special importance since it causes not only the switchover between feeders, but it also shows how well the system works as an integrated system, i.e., how well all PQDs interact during the disturbance. The DVR output will be forced to zero by a signal from the transfer switch, indicating that the HSMTS is in the process of transferring from one source to another [Fig. 14(d)].

This simple approach of a custom power park has an out-standing response to any severe or no severe power disturbance, guaranteeing a high-quality voltage supply. Voltage sags down to a retained voltage of 62% are compensated by the DVR, main-taining the critical customer bus voltage at 100%. Voltage sags 62% and below produce a transfer to the alternate feeder.

Transfers to the alternate feeder involve the operation of all three PQDs in the following manner:

1) During the detection time or sensing time, i.e., first stage of the voltage sag, the DVR compensates the bus voltage, within its limits.
2) The DVR will stop injecting voltage when the transfer signal is activated by the HSMTS.
3) When the transfer is complete, the voltage recovery seen by the critical customer is compensated by the DVR. Meanwhile, the ASVC injects the reactive power into the system, for voltage support purposes, so other customers at the alternate feeder do not experience any significant long voltage drops.

Thus, the critical load experiences a short duration voltage sag (less than two cycles), guaranteeing the ride-through of the system, without causing any customer downtime [Fig. 14(c)]. In the case of critical active loads, as in this simulation case, the voltage at the site is supported when the line is open. This is primarily due to the fact that the flux in an induction motor decays when it is not connected to the line. Thus, the rest of the passive loads in the load network are temporarily supplied by the energy stored in the motor (or motors) during the switch-over, i.e., during the two cycles mentioned before. Hundreds of simulations under different system conditions and faults were carried out. From these simulation results, important conclusions can be drawn.

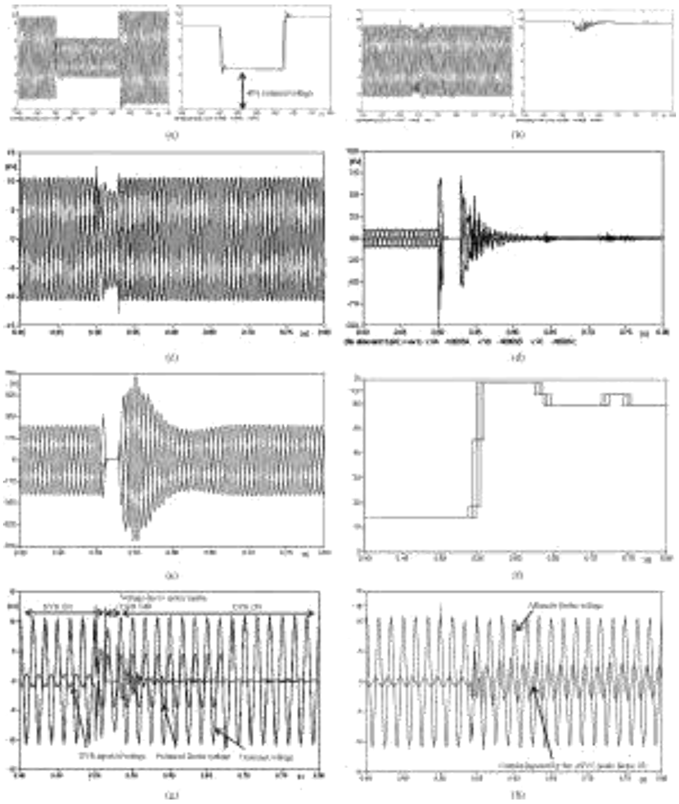

Fig. 14. Custom power park response to a three-phase voltage sag below HSMTS voltage transfer threshold. (a) Preferred feeder voltage waveforms and magnitudes. (b) Alternative feeder voltage waveforms and magnitudes. (c) Critical customer voltage waveform. (d) Voltage injected by the DVR. (e) Load current. (f) ASVC equivalent capacitance. (g) Phase A voltage waveforms. (h) Phase A ASVC voltage and current waveforms.

1) The DVR not only must be designed and sized to handle voltage down to a retained voltage of 62% but also to be able to withstand inrush currents that can double the steady-state load current. By inrush current, we mean the post-transfer inrush current, which is due to saturation effects (not considered in this simulation) plus the additional pull-out torque of the motor. This inrush current can cause the DVR to trip off line if it surpasses the DVR overcurrent limits [see Fig. 14(e)].

2) The ASVC must be sized to guarantee the bus voltage support when the full critical customer load is transferred to the alternate feeder.

3) There is no need for a supervisor system to enhance the system flexibility.

IV.CONCLUSIONS

This paper presents a first approach to the custom power park concept, using well-demonstrated performance PQDs, i.e., a DVR, an ASVC, and an HSMTS. Potential problems related to the PQD’s combined operation working in close electrical proximity, in addition to coordination solutions, can be summarized as follows.

1) There is no need for a supervisor system in this first approach. However, a minimal set of communication signals between the DVR and the transfer switch seem to be necessary to enhance the flexibility of the system and ensure that they compliment each other, particularly at the capability boundary of each device.

2) The ASVC can operate without any coordination be-tween the other two PQDs.

3) Post-transfer inrush currents can exceed the DVR's overcurrent thresholds, causing its offline trip. The DVR should be sized to handle not just a percentage of voltage sags but high inrush currents for a few cycles as well.

The drawbacks of the custom power park model are as follows.

1) The DVR is modeled as three independent phase voltage sources of controllable magnitude and phase.

2) The TCR in the ASVC is modeled as a variable inductor, thus ignoring the effect of the current harmonics injected by the ASVC into the system performance.

3) The HSMTS is set to transfer to the another feeder only for voltage disturbances (voltage sags below 62%).

4) The active load (or spinning load) at the critical customer is modeled as a single induction motor.

Finally, the applications of the research conducted in this paper are as follows.

1) The paper presents a simple first approach to the custom power park concept, based on commercially available PQDs.

2) Results can be used to help develop premium power parks designed to elevate power to a different level with a reasonable cost.

REFERENCES

[1] Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV through 38 kV, IEEE P1409 Distribution Custom Power Task Force, 2003.

[2] The Electricity Technology Roadmap Initiative. A Guide for Developing the Science and Technology of the Future, EPRI, 1999.

[3] Contingency Planning Research (CPR) and Contingency Planning & Management Magazine (CPM), 2001 Cost of Downtime.

[4] Custom Power—State of the Art Cigre WG14.31, 2000.

[5] C. Alvarez, J. Alamar, A. Domijan Jr., A. Montenegro, and Song, "An investigation toward new technologies and issues in power quality," in Proc. 9th Int. Conf. Harmon. Qual. Power, vol. 2, 2000, pp. 444–449.

[6] Y. Mishima, H. Kita, and J. Hasegawa, "A proposal of interior structure of quality control center in the FRIENDS," in Proc. Int. Conf. Elect. Eng., vol. 1, Kyongju, Korea, Jul. 1998, pp. 346–349.

[7] T. Ise and K. Tsuji, "Flexible, reliable and intelligent electric energy delivery system: Configuration of quality control center," in Proc. 61st Amer. Power Conf., Chicago, IL, Apr. 1999.

[8] T. Ise, Y. Hayashi, and K. Tsuji, "Characteristics and location of the quality control center using three-phase four-wire AC system," in Proc. Int. Conf. Power Syst. Technol., vol. 2, 2000, pp. 661–666.

[9] "Premium Power Park (PPP): Phase 1 – Application Methodology," EPRI, Palo Alto, CA.

[10] V. Kaura and V. Blasko, "Operation of a phase l

[11] ocked loop system under distorted utility conditions," IEEE Trans. Ind. Appl. , vol. 33, no. 1, pp. 58–63, Jan./Feb. 1997.

[12] (2003) Fastran 25 High Speed Transfer Switch. Joyslyn High Voltage. [Online]. Available: http://www.joslynhivoltage.com/PDFFiles/DB770-512fastranbrochure.PDF

[13] (2003) Cycle + Automatic Transfer Switch. Powell Industry, Inc.. [On-line]. Available: http://www.powellesco.com/pdf/cycle_plus.pdf

[14] G. Bizjak, P. Zunko, and D. Povh, "Circuit breaker model for digital simulation based on Mayr's and Cassie's differential arc equations," IEEE Trans. Power Del., vol. 10, no. 3, pp. 1310–131.5, Jul. 1995.

[14] Alternative Transient Program (ATP) Rule Book, Canadian/American EMTP User Group.