COMPARATIVE ANALYSIS OF DYNAMIC VOLTAGE RESTORER SUPPORTED WITH BESS AND SUPER CAPACITOR

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ABSTRACT
Dynamic Voltage Restorer (DVR) plays key role in resolving power quality issues like voltage sag, swell, harmonics, interruption etc., which are detrimental in the power system if uncompensated. Further, they improve power transfer capacity of the transmission line. In this research article, the performance of the DVR is analysed under two different scenarios: Battery Energy Storage supported and Super-Capacitor supported dc link. A three phase PLL is used for generating reference signals for the Synchronous Reference Frame based PWM signals. The proposed system is tested through simulation using MATLAB/SIMULINK and the results are compared.

Key words: Power quality, Series compensation, Dynamic voltage restorer, in-phase injection, BESS, Super capacitor.

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1. INTRODUCTION
With technological advancements and globalisation, prices of electric appliances have come down drastically. Though this also resulted in increased energy demand, which boosts development index, it also resulted in heavy utilization of power electronic based appliances. These appliances produce harmonics, demand higher reactive power and hence leads to large currents in the distribution lines. If the transfer capability of the lines are not improved, it will result in power quality issues as well. The secondary effect of it is supply interruptions. To
Comparative Analysis of Dynamic Voltage Restorer Supported With Bess and Super Capacitor

avoid black outs, governments are encouraging distributed energy sources [1], [2]. This resulted in large-scale injection of renewable energy sources into the power system. However, this results in more power quality issues at the distribution side due to intermittent nature of renewable energy sources [3]. Hence, power quality issues arise from both transmission and distribution sides and appropriate measures are to be taken from either sides to mitigate those issues. Critical loads such as hospital loads, chemical industries, military applications etc., are greatly affected by these power quality issues. Especially, chemical processes result in loss of entire batch of the process resulting in loss of time, energy and money [4].

In general, passive filters, capacitors, are installed to smooth out harmonics, reactive power and to improve voltage profile. However, they result in more losses and the compensation is based on average control rather than instantaneous control. In addition, each device offer only one solution, resulting in infrastructure burden on the consumer as well as grid operator. Further, controlling of passive filters is difficult as it involves mechanical switches that are not fast acting in nature [5]. With advanced in control techniques for controlling power electronic converters, active devices offer multiple solutions with a single device. They also provide redundancy advantage in the system and hence reduces financial burden on both grid operators and consumers.

FACTS devices offer transmission-side solution while custom power devices (CPD) offer from consumer side. In general, power electronic devices controlled by the utility are termed as FACTS devices, whereas those controlled by consumers are termed as CPD. They offer instantaneous compensation unlike passive filters that offer average control. The commonly used CPDs are Uninterruptible Power Supplies Dynamic Voltage Restorers and Active Power Filters. While Active power filters are used to mitigate harmonics and reactive power compensation, UPS and DVR are used to compensate other power quality issues like Sag, swell, and unbalanced loads. In this article, the control of DVR for voltage deviations due to step disturbances has been presented. DVR offers a better solution in reducing industrials processes susceptibility to supply voltage sags [6], [7], [8]. The power electronic converter of DVR can be either VSI converter or Modular Multilevel Converter (MMC) [9].

2. MODELLING OF DVR
The schematic of a DVR-connected system is shown in Fig 1a. When the system voltage, $V_s$, is affect due to step loads leading to sags/swells, a compensating voltage, $V_{DVR}$, is injected by the DVR such that the voltage magnitude $V_L$ across critical load remains constant irrespective of voltage at the point of common coupling (PCC). The injected voltage of the DVR can be written as

$$V_{dvr} = V_L + I_L Z_L - V_S$$

Where,

$V_{DVR}$ = Injected voltage

$V_S$ = Source Voltage

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The DVR is a combination of a low pass filter, a power electronic converter, an energy storage device and an injection transformer. The energy storage device can be a battery-energy storage system, super capacitor or a photovoltaic system. During the normal operation, the DVR consumes active power required to maintain the DC link voltage [12]. Under abnormal conditions, the stored energy is used to compensate the reactive power and harmonics produced by other non-linear loads in the vicinity of the sensitive load under consideration [13].

3. CONTROL AND DESIGN OF DVR

The compensation for voltage sags/swells with DVR can be accomplished by injecting reactive power or absorbing the active power respectively [14], [15]. A quadrature injection results in injecting reactive power while the in-phase injection results in active power. The injected active power from the energy storage device of the DVR is accumulated during normal operation or through a self-sufficient energy source viz. Photovoltaic system, Fuel Cell system. In case of super-capacitor or BESS, minimum energy principle has to be employed to reduce the storage losses. The design of DVR includes ratings of injection transformer, storage device and converter.

Fig. 2 demonstrates the control diagram of the DVR in which the synchronous reference frame theory is designed for generating modulating signal. PCC Voltage, $V_s$ and critical load voltage $V_L$ are fed back to controller for pulse generation. Direct and quadrature components of PCC voltage and load voltages are derived using transformation and is passed through low pass filter for eliminating low frequency components like 100 Hz. The filtered direct voltages component and quadrature component are then compared with dc link voltage and reference quadrature component respectively. The resultant voltage components are then transformed back to a-b-c reference frame for PWM generation [16].

$$K_{cp}^{-1} = \begin{bmatrix}
\cos(\theta) & \sin(\theta) & 1 \\
\cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\
\cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \\
\end{bmatrix}$$  \hspace{1cm} (2)
The DC link voltage that is reduced due to switching losses and injection of active component of current has to be maintained constant. A PI controller is implemented to regulate the DC link voltage of the super-capacitor. The governing equation is given in eq.(3) as:

$$V_{\text{cap}}[k] = V_{\text{cap}}[k-1] + K_p (e_{\text{vdcl}}[k] - e_{\text{vdcl}}[k-1]) + K_i e_{\text{vdcl}}[k]$$

(3)

Where,

$$e_{\text{vdcl}}[k] = V_{dc} - V_{dc}[k]$$

is the DC voltage deviation at the k\textsuperscript{th} sample. $K_p$ and $K_i$ are the DC-link PI controller gains.

$$V_{d}^* = V_{\text{dcl}} - V_{\text{cap}}$$

(4)

As the voltage compensation is done using the quadrature component, a PI controller is considered to reduce the load terminal voltage’s amplitude, $V_L$. Voltage regulation is achieved using the controller output, $v_{qr}$.

$$V_L = \sqrt{\frac{2}{3}} \left( V_{L_a}^2 + V_{L_b}^2 + V_{L_c}^2 \right)$$

(5)

$$V_{\text{q}}[k] = V_{\text{q}}[k-1] + K_p (e_{\text{vl}}[k] - e_{\text{vl}}[k-1]) + K_i e_{\text{vl}}[k]$$

(6)

Where,

$$e_{\text{vl}}[k] = V_{L}^* - V_{L}[k]$$

is the load voltage deviation at the k\textsuperscript{th} sample.

$K_p$ and $K_i$ are the PI controller gains.
4. RESULTS AND DISCUSSIONS

The proposed DVR as shown in Fig. 3 is implemented in MATLAB/Simulink environment. The system is tested for various power quality issues like Sag and Swell with Super-Capacitor support and BESS support and the efficacy of both the systems are evaluated. The design values of the DVR are taken from [17]. The PI controller gains are tuned using optimization Toolbox in MATLAB.

4.1. Capacitor Supported DVR

4.1.1 Sag Condition

Whenever a step load is suddenly turned on, it draws huge inrush currents resulting in sag at the PCC. In the system under consideration, a sag is introduced at 0.35 sec with 5 cycle duration till 0.45 sec as shown in fig. 4. The DVR draws current from the utility during normal period for charging the Super-capacitor. Once, the sag is generated, the proposed DVR injects an in-phase voltage at the PCC so that voltage profile of the critical load point is improved as shown in fig.4. The results show the performance of the DVR under sag condition.
4.1.2 Swell Condition
Whenever a step load is suddenly removed or when a distributed sources starts injecting power into the system, it a swell is developed at the PCC. In the system under consideration, a swell is introduced at 0.35 sec with 5 cycle duration till 0.45 sec as shown in fig. 5. The DVR draws current from the utility during normal period for charging the Super-capacitor. Whenever, the sag is genearted, the DVR injects an in-phase voltage at the PCC so that voltage profile of the critica load point is improved as shown in fig.5. The results show the performance of the DVR under swell condition.

Figure 4 Performance of Super Capacitor-connected DVR with in-phase injection under Sag condition

Figure 5 Performance of Super Capacitor-connected DVR with in-phase injection under Swell condition
4.2 BESS supported DVR

4.2.1 Sag Condition

In this scenario, the energy storage device is taken to a battery and the sag conditions are imposed on the system as in the SC supported DVR. A sag is introduced at 0.25 sec with 5 cycle duration till 0.35 sec as shown in fig. 6. The DVR draws current from the utility during normal period for charging the battery. Once, the sag is generated, the proposed DVR injects an in-phase voltage at the PCC so that voltage profile of the critical load point is improved as shown in fig. 6. The results show the performance of the DVR under sag condition. From the results, it can be seen that the battery is drawing limited current from the utility as the voltage across the battery is maintained almost constant.

Figure 6 Performance of BESS-connected DVR with in-phase injection under Sag condition

4.2.2 Swell Condition

Similarly, a swell condition is introduced at 0.25 sec with 5 cycle duration till 0.35 sec as shown in fig. 7. The DVR draws current from the utility during normal period for charging the Super-capacitor. Whenever, the sag is generated, the DVR injects an in-phase voltage at the PCC so that voltage profile of the critical load point is improved as shown in fig. 7. The results show the performance of the DVR under swell condition.
Comparative Analysis of Dynamic Voltage Restorer Supported With Bess and Super Capacitor

5. CONCLUSION
With change in the load nature to electronic equipment like computers, adapters and LED bulbs etc., harmonic content in the power supply has drastically increased. This results in increased reactive component of current drawn from the utilities. This phenomenon is further escalated with distributed energy sources in the system that are mostly operated with power electronic converters. In this paper, a DVR is placed at the sensitive loads to compensate the voltage fluctuations like sag, swell and harmonics. The dc link voltage of the DVR is maintained using two scenarios: Super-Capacitor and BESS. The proposed system is validated using MATLAB/Simulink environment. In-phase injection method is used for generating the PWM signals to the converter to reduce the rating of DVR. The results showed that BESS supported system is proven better than Super-capacitor supported system as the dc link voltage with BESS is maintained smoothly. The proposed system can be improved by using Photovoltaic/PEM Fuel Cell based dc link to reduce the dependency on the utility and hence can reduce the VAR utilization from the grid resulting in energy and cost savings to the consumer.

REFERENCES


