COMPENSATION OF VOLTAGE VARIATIONS IN DISTRIBUTION SYSTEM BY USING DVR BASED SEPARATE ENERGY STORAGE DEVICES

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I. INTRODUCTION

Power systems have been experiencing good changes in electric power generations, transmissions, and distributions. For electrical load growth and higher power transfer in a largely interconnected network lead to complex and less secure power system operation. Power system engineers facing challenges seek solutions to operate the system in more a flexible and controllable manner. So role of energy storage devices play important role as Energy storage appears to be beneficial to utilities since it can decouple the instantaneous balancing between supply and demand. Therefore increased asset utilization is allowed, that facilitates the renewable sources penetration and improves the flexibility, reliability and efficiency of the grid long and short-duration voltage

Variations by abrupt increases in loads such as faults or short circuits, starting of motors, or turning on of electric heaters or they are caused by abrupt source impedances is increase, which are caused by a loose connection. Power quality issues are divided into two categories voltage quality and frequency quality. Voltage quality issues are related with voltage sag, voltage swell, under voltage and over voltage while frequency quality issues are related with harmonics and transients. One of

Abstract— The Separate Energy Storage Device (SESD) based Dynamic Voltage Restorer (DVR) used to protect consumers from the grid voltage fluctuations like Long and Short-Duration Voltage Variations. This paper analyses the operation principle of the SESD based DVR and its design is based on simple PI control method and decision making switch to compensate Long and Short-Duration Voltage Variations. During short-duration voltage variation super capacitor and fuel cell hybrid system is used to compensate the fault. In the same way during long-duration voltage variation photovoltaic (PV) system or backup battery or other grid is used to compensate the fault based on the availability. Using MATLAB/SIMULINK, the models of the SESD based DVR is establish, and the simulation tests are performed to evaluate the system performances.

Keywords- DVR; Long and Short-Duration Voltage Variations; Pulse-width modulated (PWM); Decision making switch; Grid; Bidirectional Isolated DC–DC Converter, SESD.
the most imperative power quality issues is voltage sag which is occur due to its usage of voltage sensitive devices.

Energy storage devices can be classified into two diff categories, depending upon their application: short term response energy storage devices and long-term response energy storage devices. Short term response energy devices which include flywheel, super capacitor, SMES whereas long term response energy storage devices include compress air, hydrogen fuel cell, batteries, Redox flow. Here we are more concern with short term response energy devices.

For Long and Short-Duration Voltage Variations compensation, the DVR which acts as series-connected topology is a more cost-effective solution. In this paper, a SESD unit is introduced as the energy storage unit of the DVR. Application of SESD for power conditioning with DVR is put forth. The dynamic response of the SESD based DVR on voltage sag and swell is evaluated using MATLAB simulation.

The energy storage devices are split in to two Types direct energy storage and indirect energy storage as shown in Fig.1.

Fly-wheel batteries, ultra capacitors & capacitors (combined with DG devices) are comes in small categories.

(ii) Medium categories (10MW < energy < 100 MW): Large-scale batteries, lead-acid, NAS and Redox are come in medium categories.

(iii) Large categories (≥ 100 MW): Compressed Air Storage (CAS), Pumped Storage are comes in large categories.

II. SESD WITH DVR

The basic structure of a DVR based SESD is shown in Fig.3. It consists of Battery storage, capacitors bank, voltage source inverters (VSI), low pass filter and a voltage injection transformer, Decision making switch, grid, PV.
In order to mitigate the simulated voltage variation in practical application, a discrete Pulse Width Modulation-Based control scheme is implemented, with reference to DVR as shown in Fig 4. The aim of the control scheme is under the system disturbance to maintain a constant voltage magnitude at the sensitive load point. The control system only measures the rms voltage at load point; Long and Short-Duration Voltage Variations is created at load terminals by a various phase fault as shown in Fig.4. Load voltage is converted into per unit quantity and is passed through a sequence analyzer.

The magnitude is then compared with reference voltage through which error signal is fed to PI controller. This voltage is then fed to triggering circuit. PWM control technique is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal voltage at the load terminals. The range of Chopping frequency is a few Kilo Hertz. The PI controller is controls the IGBT to maintain 1 per unit voltage at the load terminals that is considered as base voltage is equal to 1 per unit. The DVR control system exerts a voltage angle control as follows:

\[ V_A = \sin(\omega t + \delta) \]  \hspace{1cm} (3)
\[ V_B = \sin(\omega t + \delta - 2\pi/3) \]  \hspace{1cm} (4)
\[ V_C = \sin(\omega t + \delta + 2\pi/3) \]  \hspace{1cm} (5)

An advantage of a proportional plus integral controller is that integral term causes the steady-state error to be zero for a step input. The input for PI controller is an actuating signal which is the difference between the Vref and Vin. The controller block output is of the form of an angle \( \delta \), in the three phase voltages which introduces additional phase-lag/lead. The error detector output is
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The transformers $T_1$ and $T_2$ with independent primary windings as well as series-connected secondary windings are employed to realize galvanic isolation and boost a low input voltage to the HV dc bus. A dc blocking capacitor $Cb$ is added in series with the primary winding of $T_2$ to avoid transformer saturation caused by asymmetrical operation in full-bridge circuit. The voltage doublers circuit utilized on the secondary side is to increase voltage conversion ratio further. The inductor $L_2$ on the secondary side is utilized as a power delivering interface element between the LV side and the HV side. According to the direction of power flow, the proposed converter has three operation modes that can be defined as boost mode, SC power mode, and SC recharge mode. In the boost mode, the power is delivered from the FCs and SCs to the dc voltage bus.

In the SC power mode, only the SCs are connected to provide the required load power. When the dc bus charges the SCs, the power flow direction is reversed which means the energy is transferred from the HV side to the LV side, and thereby the converter is operated under the SC recharge mode.

Fuel cell design is modeling shown in in Fig.6


Fig. 6. Fuel cell simulation model.
Due to the advantages of low emission and little mechanical parts, the PV power generation becomes a promising renewable energy technique. However, the PV current changes with the solar irradiations level, whereas the PV output volt changes with the temperature of the PV module. So, there is fluctuation in the PV output power due to the stochastic climatic conditions. To compensate the inherent fluctuation of PV output power and provide the electricity with high quality, the energy storage system such as the battery system must be used. PV with converter simulation model is shown in Fig.7.

![Fig. 7. PV with converter simulation model.](image)

Mini PV system was designed for 30V. That 30V output is fed in to isolated DC-DC converter that converter output is 500Vdc. And then Battery is connected to floating condition and with connected grid by via VSC converter.

![Fig. 8. Voltage source controller simulation model.](image)

Fig. 8. Voltage source controller simulation model.

VSC converter is used to act as a inverter and rectifier operation based on the source availability. For voltage source controller get the grid voltage, current and DC voltage. Compare the dc and grid side voltages pulse patterns are varied.

Based on the pulse angle converter acts as a inverter and rectifier. Fig. 9. Shows Grid connected VSC converter simulation model

![Fig. 9. Grid connected VSC converter simulation model.](image)

V. DECISION MAKING SWITCH

Decision making switch simulation model is shown in Fig.10. This decision making switch control is used to allow which energy source is supply for compensation during fault condition. The short duration voltage variation is compensated only by using fuel cell and super capacitor hybrid combination in the same way for long duration voltage variation compensated by various
choices like battery alone, PV alone and grid alone based on the availability.

VI. SESD BASED DVR TEST SYSTEM

Single line diagram of the test system 13 kV composed DVR Based on SESD, 50 Hz generation system, feeding two transmission lines through a 3-winding transformer connected in star/delta/delta, 13/115/115 kV. Such trans lines feed two distribution networks through two transformers connected in delta/star, 115/11 kV and then 11KV/500V. We verify the working of DVR for voltage compensation at 0.44 ohms fault resistances for fixed time duration of .08 and .3 secs. The DVR performance in presence SESD is analyzed for symmetrical three phase to ground fault.

Fig. 11 is MATLAB/SIMULINK diagram of SESD based DVR for compensating Long and Short-Duration Voltage Variations. The first simulation was carried out without SESD based DVR and a three phase to ground fault is applied to the system at point with fault resistance of 0.44Ω for time duration of .08 and .3 secs. which result voltage sag as shown in Fig.5. The second simulation is carried out at the same scenario as above but now in this case SESD based a DVR is introduced to compensate the voltage sag occurred due to the three phase to ground fault which is as shown in Fig. 11.

The backup battery voltage for fully charged condition shown in Fig.12. Mini photovoltaic array output (30V) shown in Fig.13. PV with DC-DC converter output(500V) shown in Fig.14. Fuel cell for hybrid system output(30V) was modeled corresponding output shown in Fig.15. hybrid bidirectional dc–dc converter topology output is shown in Fig.16.

For fault condition in transmission line the voltage level is shown in Fig.17. The decision making switch controller pulse output is shown in Fig.18. Fault clearing for only short voltage variation by used SESD based DVR is shown in Fig.19.

Fault clearing SESD Based DVR (Battery Source alone) in this condition only backup battery support for clearing long voltage variation and absents of Grid and PV system, short voltage response is compensating super capacitor and fuel cell hybrid system shown in Fig.20.

Fault clearing SESD Based DVR (PV Source alone) in this condition only PV support for clearing long voltage variation and absents of Grid and Battery short voltage response is compensating super capacitor and fuel cell hybrid system shown in Fig.21. Fault clearing SESD Based DVR (Grid Source alone) in this condition only Grid support for clearing long voltage variation and absents of Battery and PV system short voltage response is compensating super capacitor and fuel cell hybrid system shown in Fig.22.
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Fig.11. phase-phase voltage without any fault.

Fig.12. Backup battery voltage output.

Fig.13. PV output voltage.

Fig.14. PV output with converter output voltage.

Fig.15. Fuel cell output voltage.

Fig.16. Hybrid bidirectional dc–dc converter topology output.

Fig.17. Phase-phase voltage with fault condition.

Fig.18. Decision making switch pulse output.
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Fig. 19. Fault clearing (Short voltage variation).

Fig. 20. Fault clearing SESD Based DVR (Battery Source alone).

Fig. 21. Fault clearing SESD Based DVR (PV Source alone).

Fig. 22. Fault clearing SESD Based DVR (Grid alone).

CONCLUSION
A new design which incorporates a separate energy storage device (SESD) as to mitigation Long and Short-Duration Voltage Variations and enhances power quality of a distribution system. SESD based on DVR has been presented. The Simulation results prove that the SESD can be a useful alternative DC source for the DVR.

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