Development of Power Quality using Power Electronics Transformer based DVR

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Abstract

Modern large energy systems such as electricity grids and electrified transportation encounter increasing processed power in multi-physics domains, such as electrical, mechanical, thermal, and chemical. Although many systems are becoming predominantly electrical dependent, an integrated multi-physics energy approach creates additional avenues to higher power density, system efficiency, and reliability. Power electronics, serving as power conversion mechanisms, are key linking subsystems consisting of electronic devices, electro-mechanical units, energy storage, etc. This dissertation first studies the use of power electronic drives to implement dynamic thermal storage as effective inertia in solar-interfaced grid-connected low-energy buildings, as an example of a stationary large energy system. Dynamic management of energy components is used to offset variability of stochastic solar resources. Emphasis is on power electronic HVAC (heating, ventilation, and air-conditioning) drives, which can act as an effective electric swing bus to mitigate solar power variability. In doing so, grid power flows become substantially more constant, reducing the need for fast grid resources or dedicated energy storage such as batteries.

Introdcution

The work defines a bandwidth over which such HVAC drives can operate. A practical band-pass filter is realized with a lower frequency bound such that the building maintains consistent temperature, and an upper frequency bound to ensure that commanded HVAC fan speeds do not update arbitrarily fast, avoid acoustic discomfort to occupants, and prevent undue hardware wear and tear. The dissertation then moves onto investigation of a mobile energy system, specifically more electric aircraft (MEA), with the purpose of evaluating thermal inertia's efficacy in a microgrid-like inertia-lacking electrical system. Thermal energy inherent in the cabin air and aircraft fuel serves as a dynamic management solution to offset stochastic load power in the MEA power system. Power electronic controlled environmental control system (ECS) drives, emulating dynamic thermal inertia, showcase a more constant generator output power, allowing potential to downsize required generator ratings. An operating bandwidth is proposed similar to that of building HVAC systems, subject to additional degrees of constraints unique on MEA. A more sensitive virtual synchronous machine control boosts desirable inertia in sub-seconds scales in the MEA power system. To validate the thermal storage as effective inertia in both stationary and mobile energy systems, comprehensive simulation studies and experimental work are conducted at multiple levels. For the energy-efficient building research platform, building electrical and thermal energy systems modeling is addressed, including solar and HVAC systems as well as batteries and large-scale thermal storage. A lab-scale power system features various update rates of a variable frequency fan drive over stochastic solar data. A full-scale multiple-day case study provides insight on potential grid-side and storage-related benefits. The simulation and experimental studies are supported by 18 months of solar data collected on sub-millisecond time scales as a basis to evaluate efficacy, determine solar frequency-domain content, and analyze mitigation of variability. For the MEA research platform, steady-state and dynamic behaviors of electrical components in the Boeing 787 power systems, including electric machines, power converters, batteries, transformers, and loads, are modeled. In particular, in-depth discussions cover a multi-timescale parametric electrical battery model for use in dynamic electric transportation simulations. An integrated thermal model within electrical components and electrical systems captures temperature variations and ECS thermal dynamics. Simulation studies based on realistic load power demand over a 5-hour mission profile show mitigation of generator power transients while maintaining relatively comfortable cabin temperature bounds. Finally a scaled-down lab power system is implemented on a microcontroller-tied industrial drive to demonstrate feasibility in a potential commercial system.

Power quality (PQ) problems have obtained increasing attentions as they can affect lots of sensitive end-users including industrial and commercial electrical consumers. Studies indicate that voltage sags, transients, and momentary interruptions constitute 92% of all the PQ problems occurring in the distribution power system. In fact, voltage sags have always been a huge threat to the industry, and even 0.25s voltage sag is long enough to interrupt a manufacture process resulting in enormous financial losses. Voltage sags are generally classified according to its depth and duration time. Typical sag can be a drop to between 10% and

90% of the rated RMS voltage and has the duration time of 0.5 cycles to 1 min. According to the data presented in majority of the sags recorded are of depth no less than 50% but deeper sags with long duration time obviously cannot be ignored as they are more intolerable than shallow and short-duration sags to the sensitive electrical consumers. Many customer power devices have been proposed to mitigate such voltage sags for sensitive loads. The most studied voltage regulator topologies can generally categorized into two groups: the inverter-based regulator and direct ac–ac converters. In several ac–ac converter-based regulators are introduced. Series-connected devices (SD) are voltage-source inverter-based regulators and an SD compensate for voltage sags by injecting a missing voltage in series with the grid. There are lots of SD topologies, and key features related to the evaluation of a certain SD topology are the cost, complexity, and compensation ability. Dynamic voltage restorer (DVR) is a commonly used SD and has been widely studied. Consumer’s equipment need pure balanced sinusoidal voltage with constant root mean square (RMS) value to have their satisfying operation.

Based on the aforementioned discussions, this paper proposes a PET based three-phase four-wire DVR to inject required compensating series voltage to the power system in such a way that continuous sinusoidal voltage is seen at load side ever at heavy fault occurrences at utility side. The proposed structure is composed of a three-phase four-leg inverter, three single-phase high frequency transformers and a three-phase high frequency harmonic filter that are connected to the utility.

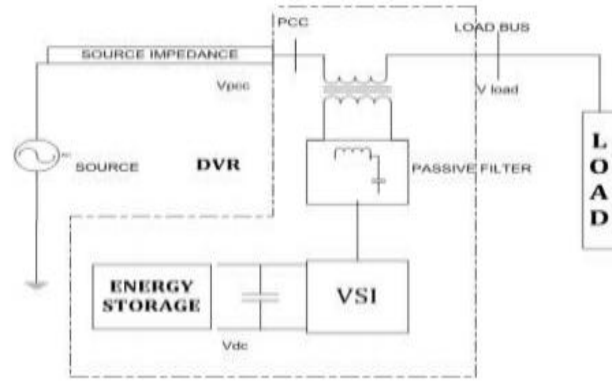


Fig.1 Basic Structure of A DVR

METHODOLOGY

In this paper a three phases four wire dynamic voltage restorer (DVR) with bidirectional power electronic transformer structure is proposed to inject required compensating series voltage to the electronic power system in such a way that continuous sinusoidal voltage is seen at load side ever at heavy fault occurrences at utility side .the proposed structure is composed of three-phase four leg inverter, three single-phase high frequency transformer , three cyclo converters and high frequency harmonic filter that are connected to the utility. Three dimensional space vector modulation (3DSVM) methods are used for pulse generation. Fourth added wire enables the DVR to compensate unbalance voltage disturbance that are custom power problems in electrical utility. The performance of the structure and applied switching scheme are verified under both balanced and applied switching scheme are verified under both balanced and unbalanced disturbances via simulation study in MATLAB software. Dynamic voltage restorer (DVR) can provide the lucrative solution to mitigate voltage sag by establishing the appropriate voltage quality level, necessary. It is recently being used as the active solution for mitigation of power quality problems.

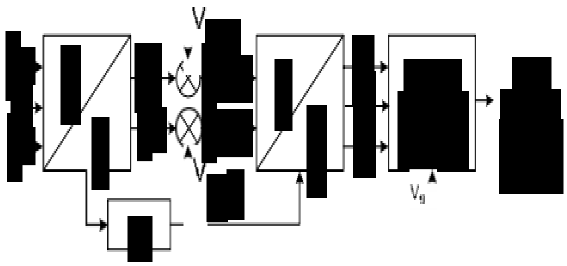


Fig. 2. Control block diagram of DVR

Three dimensional space vector modulations (3DSVM) is applied to the proposed DVR to generate switching pulses for power switches. Fourth added wire enables the DVR to compensate unbalance voltage sag and swell that are custom power quality problems in electrical utility. The aim of this paper is to propose a new approach solution to provide voltage quality for sensitive loads under balanced and unbalanced disturbance. This can be done by a three-phase four-leg converter based on 3DSVM. This technique has some advantages such as higher amplitude modulation indexes if compared with convectional SPWM techniques [l2]. The proposed DVR is shown in Fig. l. The purpose of control scheme is to maintain the load voltage at a desired value. In order to control the three-phase four-wire inverter, 3DSVM method is used that has some advantages such as more efficiency, high DC link voltage utilization, lower outpuvoltage THD, less switching and conduction losses, wide linear modulation range, more output voltage magnitude and its simple digital implementation [l2]. The block diagram of the control system used is shown in Fig. 2.

In this section, the proposed system in Fig.l is simulated in MATLAB. System parameters are given Table 1. It should be noted that the series transformers are operating at switching frequency and in linear region. Fig. 8 shows the simulation results under balance voltage sag condition. In this case, 50% voltage sag has been considered for each phases. Utility voltage, injected voltage and load voltage are shown, respectively. It is clear that the load voltage is restored to the nominal condition (before sag occurrence) after a time lower than a half cycle. It shows the simulation results under unbalance voltage sag condition with the values of 60%, 50% and 40% on phases a, b, and c, respectively. As can be seen, under such conditions, this structure injects unbalance voltage in such a way that the load voltage remains balanced and sinusoidal and doesn't sense the voltage sag

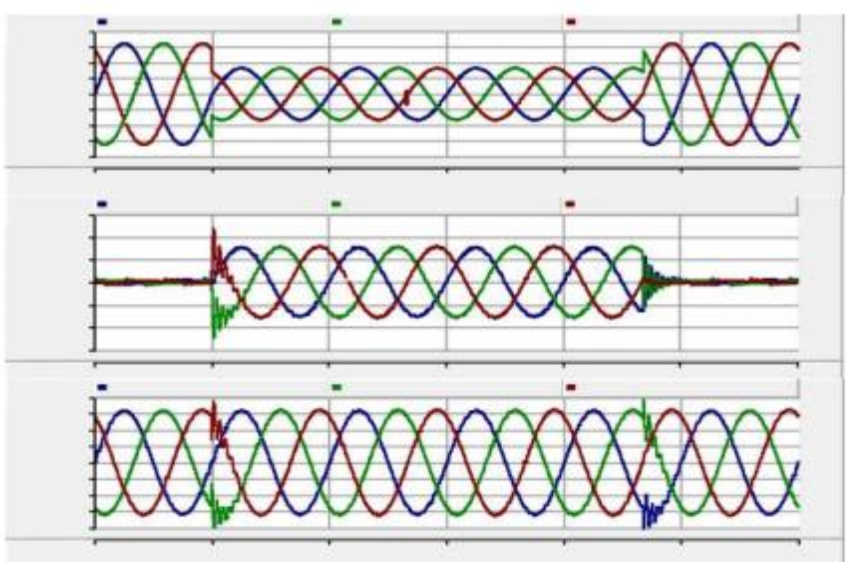
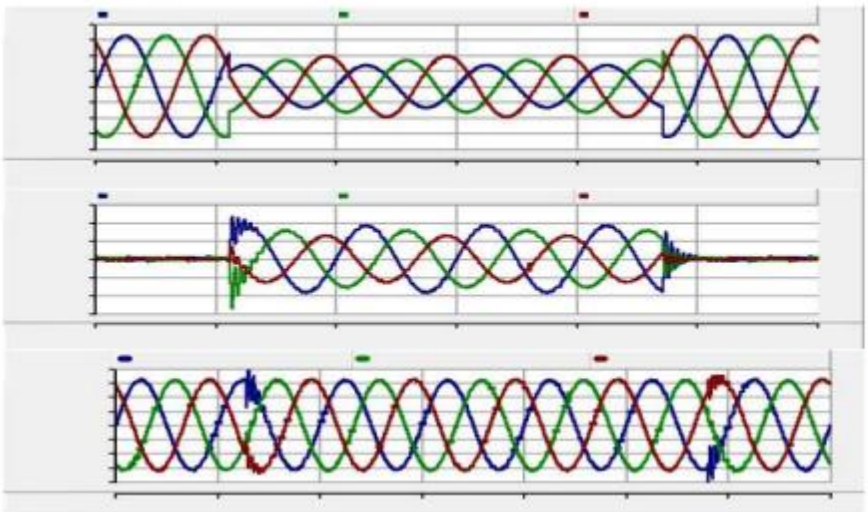


Fig 4. Simulation results under balanced sag (a) utility voltages (b) injected voltages (c) load voltages



CONCLUSION

In this paper, a three-phase four-wire DVR is presented to compensate the balanced and unbalanced sag and swell voltage using three dimensional space vector modulations. The performance of DVR is validated through simulations in MATLAB and the results verify the analysis. According to the results, DVR injects appropriated series voltage during utility voltage disturbance and maintains the load voltage at desired value. Also the THD values of the load voltage are less than the standard values.

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