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Photovoltaic based dynamic voltage restorer with power saver capability using PI controller

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ABSTRACT

In this paper, a photovoltaic (PV) based dynamic voltage restorer (DVR) is proposed to handle deep voltage sags, swells and outages on a low voltage residential distribution system. The PV based DVR can recover sags up to 10%, swells up to 190% of its nominal value. Otherwise, it will operate as an Uninterruptable Power Supply (UPS) when the utility grid fails to supply. It is also designed to reduce the usage of utility grid, which is generated from nuclear and thermal power stations. PV based DVR system is comprised of PV system with low and high power DC–DC boost converter, PWM voltage source inverter, series injection transformer and semiconductor switches. Simulation results proved the capability of the proposed DVR in mitigating the voltage sag, swell and outage in a low voltage distribution system.

1. Introduction

Dynamic voltage restorer (DVR) can provide the most cost effective solution to mitigate voltage sags, swells and outages by establishing the proper voltage quality level that is required by sensitive loads. Problems facing industries and residential regarding the power qualities are mainly due to voltage sag, short duration voltage swells and long duration power interruptions [1]. Particularly Tamilnadu, India, has more than 3 h of power interruption in a day. This may occur in developing countries, where the generated electrical power is less than the demand. The above-mentioned power quality problems may disturb the process of production in industries and residences, resulting in equipment damage and loss of revenue.

Voltage sag is a sudden reduction of utility supply voltage which may vary from 90% to 10% of its nominal value. On the other hand, voltage swell is a sudden rise of supply voltage which may vary from 110% to 180% of its nominal value. According to the IEEE 519–1992 and IEEE 1159–1195 standards, a typical duration of voltage sag and swell is 10 ms to 1 min [2]. The outage refers to an interruption of power for long duration. Many research works have been carried out focusing in the design and control of DVR [3–7].

Table 1 shows the voltage variations at Mettur Thermal Power Station (MTPS) in 230 kV bus. From the table, it is observed that there is voltage sag during summer season and voltage swell during winter season. The voltage variation event in 230 kV bus is reflecting on 230 V residential distribution system in the same way. The voltage sags and swells often caused by starting of large induction motors, energizing a large capacitor bank and faults such as single line to ground fault, three phase to ground fault, double line to ground fault on the power distribution system. Voltage sag and swell in power systems produce an important effect on the behavior of sensitive loads. Tripping of power adjustable speed drives (ASD) is one of the greatest voltage sag problems, causing critical loads to stop with the resultant interruption of the manufacturing process several times a year. The resulting loss of time and production, or damaged equipment may cause significant economical losses. To solve the above problems a new method is proposed in this paper.

In general, the voltage injection from DVR compensates the voltage sag, swell and outage. However, it needs a high capacity DC storage system. In the proposed DVR design, a PV system with low and high power DC–DC boost converters are incorporated to function as a high capacity DC voltage source.

Advantages of photovoltaics are:

- Solar power is pollution free.
- Reduced production end wastes and emissions.
- PV installations can operate for many years with little maintenance, so after the initial capital cost of building of any solar power plant, operating costs are extremely low compared to existing power technologies.

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Table 1
Voltage variation events in 230 KV bus at MTPS.

Day	Voltage variation in summer (April 2010) in kV		Voltage variation in winter (December 2010) in kV	
	Maximum	Minimum	Maximum	Minimum
1.	227	217	234	226
2.	225	217	233	227
3.	229	222	232	224
4.	227	220	233	227
5.	227	220	233	229
6.	227	219	235	227
7.	228	216	234	227
8.	228	221	233	227
9.	229	220	233	227
10.	229	223	233	226
11.	227	219	233	227
12.	226	214	234	227
13.	228	214	234	225
14.	228	221	233	226
15.	228	223	233	226
16.	228	220	231	225
17.	228	220	231	227
18.	230	224	231	225
19.	230	221	231	229
20.	228	224	233	226
21.	230	223	233	226
22.	230	224	233	227
23.	231	224	234	224
24.	231	226	234	226
25.	231	225	232	224
26.	230	225	231	226
27.	229	223	232	226
28.	230	225	231	225
29.	230	225	231	225
30.	230	225	231	224
31.	–	–	231	225

Disadvantages of photovoltaics are:

- Photovoltaic cells are costly.
- Solar electricity is more expensive than other forms of small scale alternative energy production.
- Solar electricity is not produced at night and is much reduced in cloudy conditions. Therefore, a storage system is required.
- Solar cells produce DC which must be converted to AC.

The location of the proposed PV based DVR in a low voltage single phase distribution system is shown in Fig. 1.

This Paper presents a simulation model of a PV based dynamic voltage restorer capable of handling 10% voltage sags, 190% of voltage swells and outages on a low voltage distribution system. It is also designed to reduce usage of utility power in daytime. In the daytime, DVR will act as online UPS to feed the generated power in PV system to battery and load [8].

2. Proposed DVR

The block diagram of the proposed PV based DVR is shown in Fig. 2. The proposed system mainly consists of a photovoltaic array, low and high power DC/DC boost converters, battery, PWM inverter, series injection transformer, and semiconductor switches S_1, S_2, S_3, R_1 and R_2.

Tables 2 and 3 show the control signals of the semiconductor switches S_1, S_2, S_3 and R_1, R_2 respectively. The power semiconductor switches are controlled by the voltage sensor and logical components.

An injecting transformer is connected in series with the load for restoring sag and swell, and is reconfigured into parallel connection using switches S_1, S_2 and S_3 when handling outage [9]. A DVR can compensate voltage drop across a load by injecting a voltage through a series injection transformer [10]. The injected voltage is in phase with supply voltage, as shown in Fig. 3.

In normal condition, the supply voltage is equal to the load voltage with zero angle. During sag, the supply voltage decreases to a value less than its nominal value. The DVR reacts to the sag event and injects a compensating voltage V_{inj} in phase with the supply voltage to restore the voltage at nominal value. This method is very simple to implement, very fast especially in calculating the DVR compensating voltage. The injected voltage of a DVR (V_{DVR}) can be expressed as

$$|V_{inj}| = |V_{presag}| - |V_{sag}| \tag{1}$$

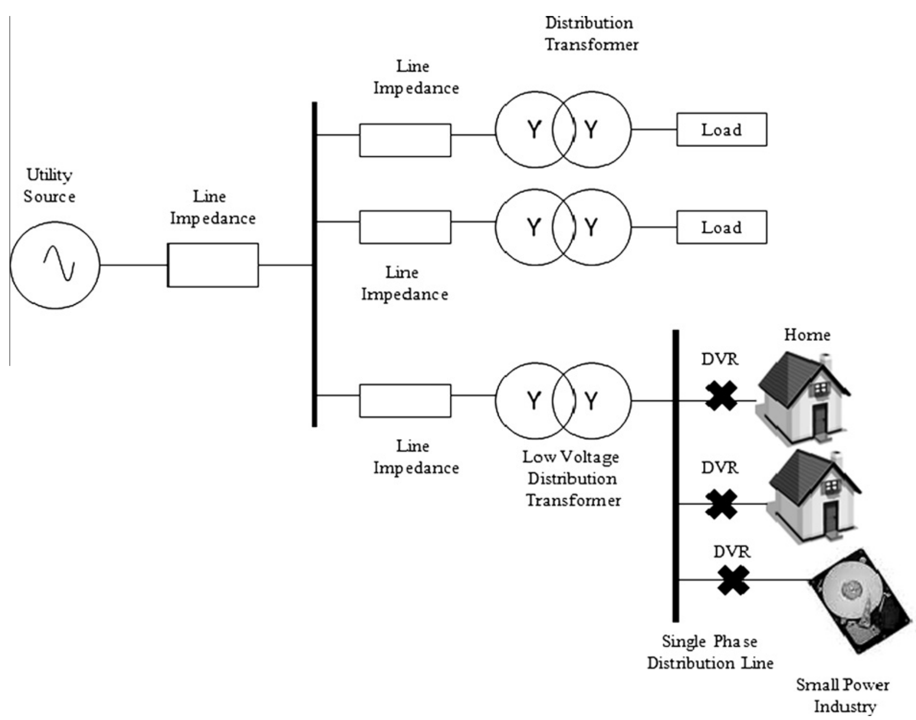

Fig. 1. Typical location of PV based dynamic voltage restorer.