An Efficient Interleaved Converter Based PV-DVR for Improving Voltage Quality

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Abstract— This paper presents a novel photovoltaic fed Dynamic Voltage Restorer (PV-DVR) is proposed to moderate deep voltage sags, voltage swells and power on a low voltage residential supply arrangement for the duration of both day time and night time. During extra voltage regulation, the proposed PV-DVR reduce the power conservation from the utility grid by disconnect the utility grid from the load in the semiconductor switch. As the PV arrangement generates average or same power to the critical load require through the day time. But the decrease of power conservation is permanently needed for the decrease of panel tariff and over all warm gas. Extra they manage of low step-up DC–DC converter. Considered interleaved high step up DC–DC converter with PI controller algorithm eliminates the drawback of conventional PV based DVR by tracking perturb & observe maximum power point (MPPT) of the photo voltaic array. Simulation and experimental results are presented to validate the improvement of the proposed system.

Key words: Photovoltaic (PV), Voltage sag, Voltage swell, power conservation, interleaved high step up DC–DC converter

I. INTRODUCTION

Dynamic Voltage Restorer (DVR) can supply the most cost valuable resolution to moderate voltage sags, voltage swells and outages by establish the proper voltage quality level that is require by the sensitive loads. PV-DVR arrangement has become a good solution for a residence or manufacturing unit. For the largest part in Tamil Nadu, India, rural areas that have a large quality of isolation and have extra regular power disturbance on each day. This could occur in the going up countries, wherever the generated electrical power is fewer than their demand. Difficulty facing industry and residence concerning the power qualities are mainly due to voltage sag, short duration voltage swell and long duration [2]. Voltage sag is defined as a rapid decrease of utility supply voltage which may vary from 10% to 90% of its actual value. Voltage swell is defined as a rapid increase of supply voltage from 110% to 180% of its actual value. According to the IEEE 519-1992 and IEEE 1159-1195 set, a characteristic time of voltage sag and voltage swell is 10 ms to 1 min [1]. The outage refers to an intermission of power for long duration. The voltage change measure record at a 230 V home low voltage distribution is observed that the voltage sag, voltage swell and outages have occur in the low voltage distribution system. The idea of utilize the DVR for voltage sag and outage improvement without PV system is obtainable [1]. The rating and plan of series injection transformer of the DVR is offered. Online type DVR has been presented to give back the voltage sag in the system [2]. The DVR without PV structure supported by the super capacitor as power storage device for power quality development in electrical supply system. The conventional DVR having following demerits: (1) The high cost DVRs are only used for the improvement of voltage instability. (2) It consumes extra power from the utility grid for the advantages of long duration voltage variation. (3) It increases the possible panel tariff and electricity demand. To overcome the demerits of the above mentioned conventional DVRs, a new idea for best operation of PV solar system inverter as a DVR for voltage sag, voltage swell and outage mitigation with significant power management has been proposed [2].

In this paper, a new interleaved DC–DC converter is proposed to control the PV solar system as DVR, consume the rated inverter ability during night time and inverter capacity remaining after excess or equal real power consumption of expensive the PV system over 8 h period. The proposed DVR, if connected at the terminals of a residence or small manufacturing unit can conserve 12.6 kW h in sunny days[3]. It reduces the potential panel tariff around $900 per year by reducing the power utilization from the utility grid. Photovoltaic system a simple interleaved dc-dc converter is connected with a function called MPPT [1].

II. BLOCK DIAGRAM DESCRIPTION

Fig. 1: Proposed block diagram
In general, there are three techniques such as pre sag, in-phase and minimum power injection technique to utilize to analyze the injection voltage of DVR. In-phase compensation technique is used to analyze injection voltage of DVR due to its easy performance and quick response in calculate the compensate voltage. A DVR be able to compensate the voltage drop across a load by injecting a voltage through a series injection transformer in-phase with the source voltage[15]. The injected voltage across the secondary of the series injection transformer is in-phase with source voltage shown in fig.2. In regular form the supply voltage (Presag) is different to the load voltage with zero phase angles. For the period of the voltage sag/swell, the supply voltage high or low to a value less than or greater than its actual value. The DVR reacts to the voltage sag/swell calculate and injects the compensate voltage injection in-phase with the source voltage to return the voltage at actual value.

\[
|V_{inj}| = |V_{presag} - |V_{sag}| \quad (1)
\]
\[
V_{DVR} = V_{inj} \quad (2)
\]
\[
V_{DVR} = |V_{presag} - |V_{sag}| \quad (3)
\]
\[
V_{inj} = \theta_{inj} = \theta_s \quad (4)
\]

### Table 1: Operation of DVR

<table>
<thead>
<tr>
<th>PV Voltage</th>
<th>R1</th>
<th>R2</th>
<th>Charging Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;14</td>
<td>1</td>
<td>0</td>
<td>Rectifier with PV array</td>
</tr>
<tr>
<td>&lt;14</td>
<td>1</td>
<td>1</td>
<td>UPS</td>
</tr>
</tbody>
</table>

### Table 2: Battery Charge control

The block diagram of the proposed PV-DVR is shown in Fig.1. The proposed system consists of a PV array, low step-up DC–DC converter Closed loop control, Interleaved high step-up DC–DC converter, PWM inverter, series injection transformer, converter control and load battery.

### III. DVR MODES OF OPERATION

**A. DVR Mode:**

In this mode, the proposed PV-DVR is utilized to control the voltage at the load side. Through this function a series injection transformer is configured in series with the load balance the voltage sag/swell [5].

**B. UPS Mode:**

In this method, the series injection transformer of PV-DVR is reconfigured in parallel to supply the ups power supply to load on during daytime and night time.

**C. Power Protection Mode:**

During additional power generation on the solar panel, the proposed PV-DVR disconnects the service network from load and it configures the series injection transformer into parallel to make the inverter operation to feed the additional energy generated by the solar panel to load.

**D. Advantages of Interleaved High Step up DC-DC Converter over DC-DC Converter:**

1) Interleaved high step up DC-DC converters are operated for high ratios, it leads to high voltage and current stress on the switch.
2) It produces high voltage gain when compared to the other boost converter.
3) To avoid the high level switching losses.
4) Ripple current rejection.
5) To reduce loss minimum

### IV. IN-PHASE VOLTAGE COMPENSATION METHOD

In general, there are three techniques such as pre sag, in-phase and minimum power injection technique to utilize to analyze the injection voltage of DVR. In-phase compensation technique is used to analyze injection voltage of DVR due to its easy performance and quick response in calculate the compensate voltage. A DVR be able to compensate the voltage drop across a load by injecting a voltage through a series injection transformer in-phase with the source voltage[15]. The injected voltage across the secondary of the series injection transformer is in-phase with source voltage shown in fig.2. In regular form the supply voltage (Presag) is different to the load voltage with zero phase angles. For the period of the voltage sag/swell, the supply voltage high or low to a value less than or greater than its actual value. The DVR reacts to the voltage sag/swell calculate and injects the compensate voltage injection in-phase with the source voltage to return the voltage at actual value.

![Fig. 2: In phase compensation to presage voltage](image)

![Fig. 3: Photovoltaic with low step up dc-dc converter](image)

**V. PHOTOVOLTAIC ARRAY MODELING**

Photo voltaic array is a arrangement which consists of extra photo voltaic cells to change sunlight into electrical energy. In the proposed DVR, photo voltaic array with a low step-up DC–DC converter is connected with a function of DC voltage source for the inverter of DVR. It is introduce between the photo voltaic and battery bank of the DC link[10-12]. The electrical energy powered by the photo voltaic array need DC–DC converter due to the varying environment of the generated solar energy, resultant from rapid change in climate conditions. By which modify the solar irradiation intensity as well as the cell working temperature illustrated in the fig.3.
The operating voltage of photo voltaic unit. The parameters VPV and IPV calculated from the output of photo voltaic array is utilized to generate control signal (Vref) for the PWM generator. The flow chart of P&O MPPT algorithm shown in fig.4. The rule of function of the P&O MPPT has been explained in [15]. The estimation of actual state (k) and previous state (k 1) of the parameters V and I are measured. The actual and previous state of the power is calculated from the product of actual and previous state V and I.

According to the condition as represented the increase or decrease of reference volt- age (Vref) is obtained. The Vref compared to a saw tooth wave with 10 kHz frequency generates the PWM pulse.

VII. PROPOSED METHOD INTERLEAVED HIGH STEP-UP DC– DC CONVERTER

During excessive current or excessive power function, interleaving of boost converters are well established. To receive benefit of the compensation of interleaving, interleaved coupled-inductor boost converter can be used. During this method, a single coupled inductor boost converter cell is treat as a cell and n such cells are coupled in parallel and operate at the constant switching frequency. More all the cells are operated at the equal duty ratio. It can be mention that due to inter leaving, the actual switching frequency as seen by the input and the output of the interleaved converter circuit is n times high than the switching frequency of a phase. Below standard or full-load condition, each of the interleaved cells uniformly shares the total output load.[13].

However less than lower output power demand condition, the number of working cells can be used for maximum efficiency operation of the individual cells. The number of parallel cells n in an interleaved converter mainly depends on the maximum power demand of the load and the maximum power rating of the interleaved cell.

In the practical coupled inductors, due to the non-ideal coupling between the primary and the secondary windings, there will be leakage inductances. This leakage inductance will cause high-voltage spikes when the switch is turned off.
The main working of this converter is to keep a constant Voltage (230 V) across the DC link of inverter. For that, a simple Control structure with PI controller is implemented in the high Step-up DC–DC converter. The control part comprised by Low Pass Filter (LPF), pulse width modulation, PI controller, comparator and relational operator. The low pass filter eliminates the high frequency component from the output of converter[14]. The comparator forms an error signal by comparing the reference and actual output of the converter. The PI controller with the proportional and integral gain of 5 and 0.1 process the error signal and generates the control signal required shown in fig.5. The relational operator generates the required duty cycle by comparing the process error signal with input supply.

<table>
<thead>
<tr>
<th>Type</th>
<th>Voltage</th>
<th>Setting time</th>
<th>Ripple Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boost converter</td>
<td>55</td>
<td>0.016</td>
<td>0.15</td>
</tr>
<tr>
<td>Interleaved boost</td>
<td>57</td>
<td>0.014</td>
<td>0.029</td>
</tr>
<tr>
<td>converter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interleaved boost</td>
<td>227</td>
<td>0.1</td>
<td>0.06</td>
</tr>
<tr>
<td>converter with vm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposed interleaved</td>
<td>400</td>
<td>0.07</td>
<td>0.25</td>
</tr>
<tr>
<td>boost converter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Comparison of Proposed Interleaved Boost Converter with Other Converter

VIII. VOLTAGE SOURCE INJECTION USING PARKS TRANSFORMATION

The control method used to keep a constant voltage magnitude at the load point, under system trouble. In the proposed controller, a discrete single phase locked loop is used to track the phase angle of the source voltage to perform the parks transformation on the measured single phase voltage[9].

\[
V_{\text{real}}(t) = V_{\text{max}} \sin(\omega t) \tag{16}
\]

\[
V_{\text{imag}}(t) = -V_{\text{max}} \cos(\omega t) \tag{17}
\]

\[
V_{\text{max}} = A_{\text{max}} \tag{18}
\]

\[
\begin{bmatrix}
V_d \\
V_q
\end{bmatrix} = \begin{bmatrix}
\sin(\omega t) & -\cos(\omega t) \\
\cos(\omega t) & \sin(\omega t)
\end{bmatrix} \begin{bmatrix}
V_{\text{real}} \\
V_{\text{imag}}
\end{bmatrix} \tag{19}
\]

The measured per unit value of supply voltage is improved into $|V_s|$, and the error is obtain from the variation of $|V_s|$ and reference voltage ($V_{\text{ref}}$). The PI controller designed by the Ziegler–Nichols tuning method processes the error and generates required angle d to drive the error to zero[9-10]. The PI controller with the proportional and integral gain of 5 and 0.1 process the error signal and generates the control signal required shown in fig.6. The generated $V_{\text{ref}}$ is utilized to produce switching pulses for VSI[6-8]. The basic idea of SPWM is to compare a sinusoidal control signal ($V_{\text{ref}}$) of normal frequency 50 Hz with a triangular carrier waveform (Carrier) with 20 kHz signal to produce the PWM pulses. When the control signal is higher than the carrier signal, the is obtain by the following equation switches are turned on, and their counter control are turned off. The output voltage of the inverter mitigate the low, voltage, high voltage, and outage.

Fig. 6: Voltage source injection

IX. SIMULATION RESULTS AND DISCUSSION

To illustrate the capacity of the PV-DVR used for voltage sag, voltage swell and outage improvement, a single phase system is considered. The proposed DVR model is simulated by MATLAB simulink to compensate voltage sag, voltage swell and outages at the load–side. The total simulation period is 1 s. In MATLAB simulink, the DVR is simulated to be in operation only when the supply voltage differs from its nominal value or when the PV array generates excessive power or equal power to the load demand. It reduces the energy consumption from the utility grid. The simulation parameters of the system proposed.

Fig. 7: PV array output with boost converter
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Fig. 8: Supply voltage, Injected voltage, Load voltage

Fig. 9: Constant Dc voltage

Fig. 10: Filter output voltage

Fig. 11: Interleaved Output with other Boost converter

A single phase controlled voltage source is used to provide a single phase variable voltage at the source end. Fig. 6 a reduced voltage (114 V) is applied, during the period 0.1–0.2 s, a raised voltage (253 V) is applied, during the period 0.7–0.8 s and zero voltage (0 V) is applied, during the period 0.3–0.6 s. The voltage sag and voltage swell at the source point is 50% and 110% with respect to the reference voltage. The inject voltage, load voltage and load current of the DVR. From the simulation results, it is observed that the load voltage is affected by the voltage change events. The PV array consists of 54 PV cells (6 × 9), 9 cells are linked in series to have a desired voltage output of 12 V and there are 6 parallel branches giving a total power of 200W the number of parallel PV arrays is increased to 15 to get 3000W power output. Photo voltaic array with interleaved high step up DC-DC boost converter can give greater output voltage. Fig. 7 shows it is observed that the proposed power generated by the PV array with 82% of efficiency and shows the discharge characteristic of the battery for various constant outputs voltage (24V), the voltage sag is formed when heavy load is connected to source. Voltage sag formed the duration of 0.3 to 0.6s .Fig. 8 shows injected voltage by using PV-DVR. The output voltage is compensated Fig.9 shows the output voltage and Fig.10 of the interleaved high step-up DC–DC converter with constant DC voltage. A control circuit is incorporated with the proposed converter to regulate the output voltage at 230 V. Fig.10 Shows constant filter voltage and compensate using dynamic voltage restorer. Fig.10 Shows proposed interleaved high step up dc-dc converter with other converter and having setting time of 0.6 and constant 400dc voltage.

X. CONCLUSION

For voltage sag/swell and outage mitigation at a houses or factories, an innovative application using a PV solar system as DVR is suggested. To track the maximum power point of the PV array, proposed interleaved high step up DC–DC converter including PI controller build P&O MPPT algorithm is realized. While the PV array produce same or too much real power to encounter the load required, proposed PV-DVR is constructed to reduce the power consumption from utility grid by means of separating the utility grid from the load via semiconductor switches. Additionally it decreases the panel cost and prevents utilization of UPS & stabilizer for the distinct tools at a house, factory and organization. The simulation results illustrate the ability of PV DVR in justifying voltage modifications.

REFERENCE


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