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RESEARCH ARTICLE

Sizing of dc-link capacitor for a grid connected solar photovoltaic inverter

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Abstract

Objective: To determine the optimum size of a dc-link capacitor for a grid connected photovoltaic inverter. **Methods**: Dc-link capacitors are considered as one of the sensitive parts of the grid connected photovoltaic systems and needs effort to design a reliable and optimal size capacitor as its reliability is concerned with the overall system reliability. The double line frequency power flows between the input and outside of a Φ grid connected PV system which produces voltage ripples at the capacitor and dc link. This voltage ripple increases temperature of passive components and dc source which affects the MPP operation of the photovoltaic modules and the system life. Therefore, it is essential to limit the voltage ripples at the input side of the system. The easiest way to limit the double frequency ripple voltage is to connect a capacitor in parallel to the PV module and the inverter which buffers the double line frequency power and supply a constant power to the inverter. This study proposed a general method for sizing a dc-link capacitor for a Φ grid connected voltage source inverter. It is seen that the capacitance is inversely proportional to the nominal dc and ripple voltage. Thus an increase in the nominal system voltage decreases the size of the capacitor and at the same time increases the voltage ripple. Therefore to limit voltage ripple within permissible limits and to ensure better system performance the dc-link capacitor must be appropriately sized. The simulations based on 3kW grid connected PV system are carried out in DIgSILENT Power Factory software. **Findings**: A capacitor of $410\mu F$ is needed to be connected in parallel with a 3kVA inverter having an nominal input voltage of 370V and maintaining a voltage ripple under 8.5%. Novelty: After determining optimized dc-link capacitor size we will limit the voltage ripple under permissible limits and hence improves the system efficiency and life of the grid connected PV system.

Keywords: Voltage source inverter; voltage ripple; Dc-link capacitor sizing; distributed generation; grid connected PV system

1 Introduction

A constant increase in the energy demand and environmental challenges favors for the distributed generation (DG) sources such as photovoltaic (PV), wind, geothermal, biomass etc. as quality electrical power [1,2]. Compared to the fossil fuel energy solar power generation has very low maintenance cost, noise free and without any moving part [3]. DG sources are installed near the load centers at distribution level compared to the traditional non-conventional energy sources such as oil, coal, gas, nuclear etc. which are installed far away from the load centers which not only reduces the fuel cost but also reduces a major share of cost utilized on transmitting the generated power [4–6]. Recently photovoltaic systems are actively researched as a sustainable power solution [7,8]. The PV sources can be operated in standalone or grid connected mode [9,10]. In order to inject the photovoltaic generated power to ac grid usually power electronic inverters are used with some standards and requirements [11,12].

A power electronic converter which converts dc power into ac power with controllable frequency and voltage is known as an inverter [13]. Inverters are classified as under,

- Voltage Source Inverter
- Current Source Inverter → An inverter feed with constant voltage having a parallel capacitor in between PV and inverter is known as voltage source inverter. → An inverter feed with constant current having an inductor in series in between PV and inverter is known as current source inverter. [12,14]

Figure 1 (a & b) shows the single stage voltage source and current source inverter topology respectively, while a two stage voltage source inverter topology is shown in Figure 1 (c).

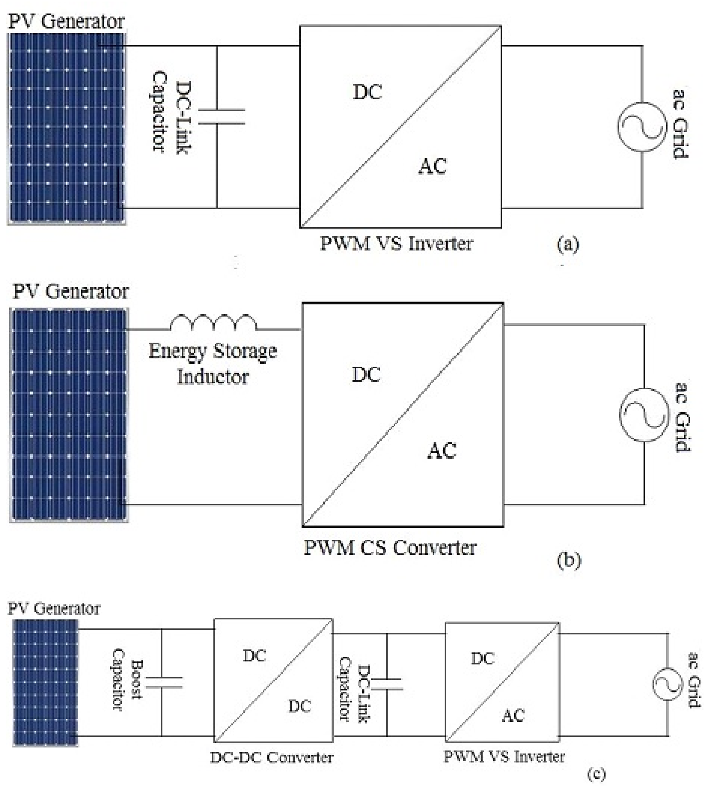

Fig 1. Inverter topologies

Distributed Generation (DG) sources such as photovoltaic (PV) systems, wind energy systems etc. produces power which is inherent intermittent and non-controllable as it depends on the weather conditions which may not meet the demand of the user at standalone or grid connected operation (15,16). In PV applications, to assure the maximum power point operation (MPP) operation of the Photovoltaic modules, the voltage ripple at the input of the inverter must be lowered (17). In order to maintain the difference between input and output power, to decrease the double frequency voltage ripple from switching action to ensure effective dc-link and provide sufficient energy at the hold-up time, the capacitors are extensively used in pulse width modulation (PWM) inverters (18–21). The aim of this capacitor connection is to increase the life of the inverter compared to the PV panel operating life time. Typically more than 20 years life of commercial PV panels is provided by manufacturers while PV inverter's life is limited by life of individual components (17). It is seen that up to 30% of electronic system failures are due to the malfunction of capacitors. Thus in system performance a reliable dc-link capacitor plays a dynamic role (22,23). Therefore for improving the system performance and reducing the voltage ripple, the size of dc link capacitor must be determined.

Typically three types of capacitors such as Aluminum Electrolytic capacitor, Metalized Polypropylene Film capacitor and Multilayer Ceramic capacitor as shown in Figures 2, 3 and 4 respectively are available which can be utilized as dc-link capacitor (16,24), however their use depends on the type of applications such as UPS, drives, solar and wind etc (25) but owing to high capacitance value and minimum cost aluminum electrolytic capacitors are extensively used. Each type of capacitor (18,26,27) reveals their merits and demerits which are tabulated in Table 1.

Table 1. Various types of capacitors with their merits and demerits

Aluminum electrolytic capacitor	Metalized polypropylene film capacitor	Multilayer ceramic capacitor
Greater capacitance per volume	Low capacitance per volume	Very low capacitance per volume
Low cost per joule	Higher cost per joule	Low cost per joule
High equivalent series resistance (ESR)	Low equivalent series resistance (ESR)	Low equivalent series resistance (ESR)
Low ripple current rating	High ripple current rating	High ripple current rating
Limited life time	Longer life time	Longer life time
Low operating temperature (85 to 105^0C)	Up to 2000^0C	Temperature ranges (-55 to 105^0C)
Less Reliability	High Reliability	More Reliability

Fig 2. Aluminum electrolytic capacitor

Fig 3. MetalizedPolypropylene Film capacitor

Fig 4. Multi layer Ceramic capacitor

The single line diagram of the proposed research work with integration of solar panels is developed in DIgSILENT power factory software using real time data is shown in Figure 5 [28].

For this purpose the connected load of one of the class of Electrical Engineering Department is considered as shown in Table 2. In order to supply a 2.5kW load an inverter of 3kVA is chosen, whose specifications are shown in Table 3 [29].

The optimum size of the photovoltaic module is determined with respect to 3kVA inverter using the metrological data as irradiance and temperature of the site. PV panels are designed under standard test conditions but the site data are below the STC therefore the power generated by PV module is always below their rated capacity. Hence the power supplied to the inverter is intermittent which produces double frequency voltage ripple on the dc side of the inverter. An increased voltage ripple affects the MPP operation of the photovoltaic module and affects the system performance. Therefore, to balance the input instantaneous power to the inverter and limit the voltage ripple an energy storage device such as capacitor is placed in parallel to the photovoltaic module and inverter. Therefore, size of the dc-link capacitor must be calculated in terms of the maximum allowable voltage ripple for the considered system.

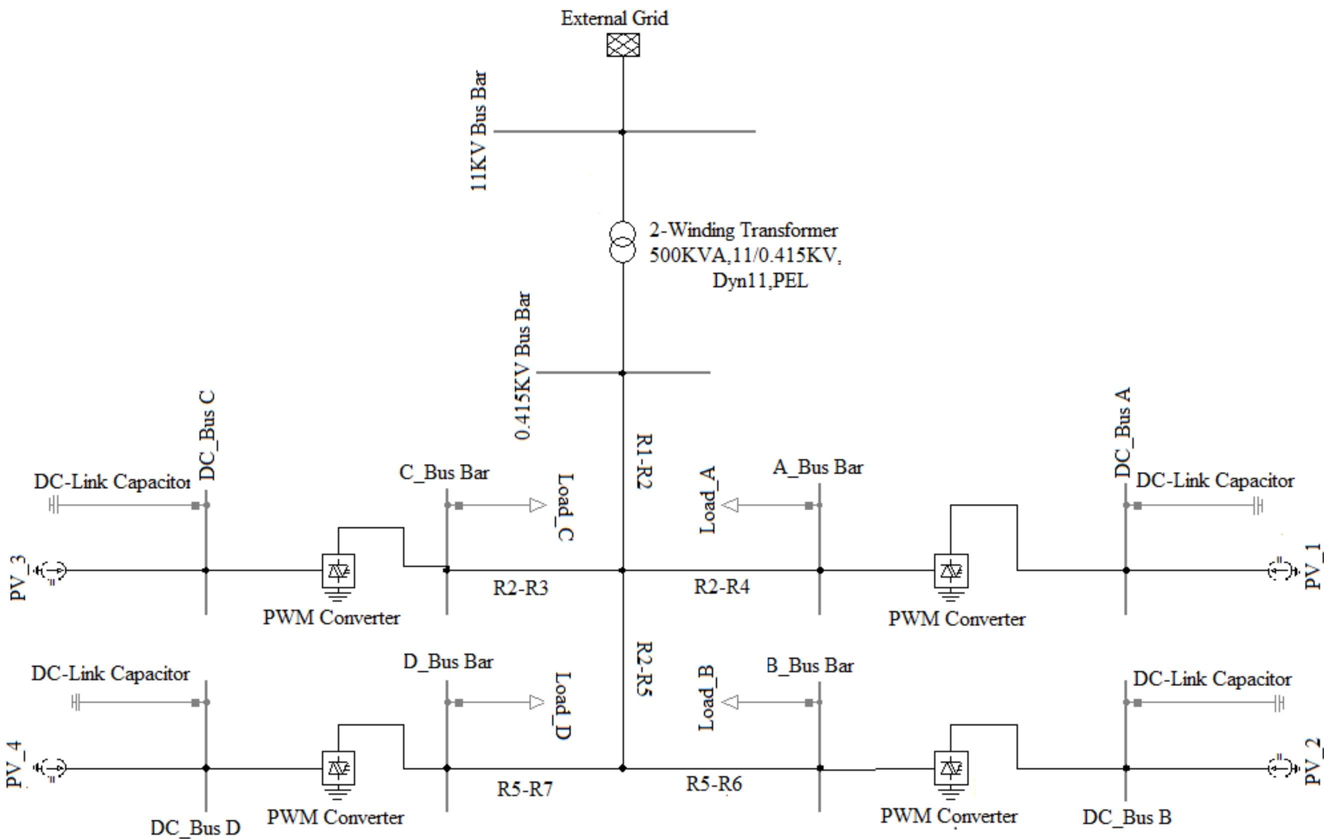

Fig 5. Model of distribution system with the integration of solar panels

Table 2. Typical load of final year class of electrical engineering department

S.No	Load name with power rating	Quantity	Total power
1	Electric Tube lights (40W)	16	640
2	Electric fans(80W)	12	960
3	Multimedia and speakers (900W)	01	900
Total load of class			2500 Watt

Table 3. 3kVA inverter stipulations

Type	Hybrid
Power Rating	3Kw
Inverter Direct Current Input	
Nominal Voltage	360 V
Peak Voltage	500 V
Start-up Voltage	116 V/150 V
Maximum Power Point Voltage	250 V to 450 V
Peak Current	13 A
Inverter AC Output	
Minimum Voltage	208,220,230,240 V
Frequency Range	47.5 to 50.2 Hz
Minimum Current	13.6 A
Power Factor	Greater than 0.99

2 Calculation of dc-link Capacitance

Figure 6 shows a grid connected power conversion system consisting of a PV generator, dc-link capacitor and a voltage source inverter supplying $V_g(t)$ and $I_g(t)$ respectively to the grid are given as (1) and (2) respectively,

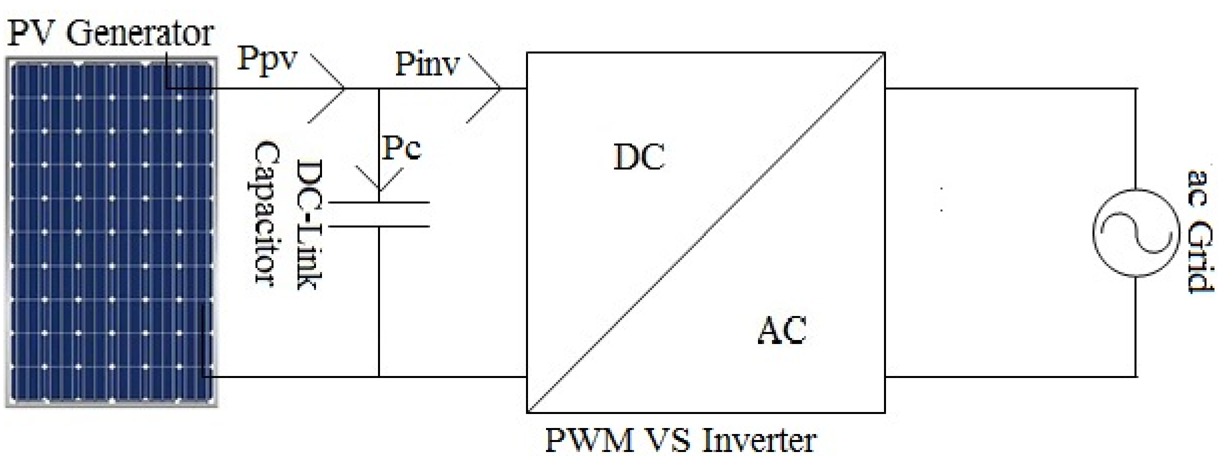

Fig 6. Grid connected power conversion system

$$V_g(t) = V_{peak} sin(\omega_g t) \tag{1}$$

$$I_g(t) = I_{peak} sin(\omega_g t + \varphi) \tag{2}$$

Where V_{peak} and I_{peak} peak or maximum voltage and current respectively, ω_g is the utility frequency which is equal to $2\pi f_g$ and angle of phase difference between current and voltage supplied to the grid is denoted by φ. The instantaneous output power is given as,

$$P_{out}(t) = V_g(t)\, I_g(t)$$

$$P_{out}(t) = V_{peak} I_{peak} sin(\omega_g t\ ) sin(\omega_g t + \varphi\ ) \tag{3}$$

For unity power factor operation angle of phase difference will be zero, therefore (3) can be rewritten as,

$$P_{out}(t) = V_{peak} I_{peak} sin^2(\omega_g t\ ) \tag{4}$$

As $sin^2(\omega_g t\ ) = \frac{1}{2}(1 - cos(2\omega_g t\ ))$

Therefore, (4) can be rewritten as,

$$P_{out}(t) = \frac{V_{peak} I_{peak}}{2}(1 - cos(2\omega_g t\ ))$$

$$P_{out}(t) = \frac{V_{peak} I_{peak}}{2} - \frac{V_{peak} I_{peak}}{2} cos(2\omega_g t\ ) \tag{5}$$

Equation (5) comprises of two parts, one is mean instantaneous ac power supplied to the grid given as,

$$P_{avr}(t) = \frac{V_{peak} I_{peak}}{2} \tag{6}$$

While the second part is the time varying oscillation of the alternating current power which is the cause of double frequency ripple given as,

$$P_{osc} = -\frac{V_{peak} I_{peak}}{2} cos(2\omega_g t\ ) \tag{7}$$

As seen from the Fig. 8 the PV generator has to supply the power to both the inverter and dc-link capacitor given as,

$$\begin{aligned} P_{pv} &= P_{inv} + P_c \\ \cdot P_{inv} &= P_{pv} - P_c \\ \cdot P_{inv} &= P_{pv} - i_c V_{dc}\ \ as\ P_c =\ i_c V_{dc} \\ \cdot P_{inv} &= P_{pv} - C_{dc} V_{dc} \frac{d\overline{V_{dc}}}{dt} \end{aligned} \tag{8}$$

By ignoring the inverter losses and maintaining a constant power at the PV generator terminals, the PV generator power and inverter power output should be equal, and that is the average instantaneous ac output power given as,

$$P_{pv} = P_{inv} = P_{out} = P_{avr}(t) = \frac{V_{peak} I_{peak}}{2} \tag{9}$$

By inserting (9) in (8), we will have,

$$P_{inv} = \frac{V_{peak} I_{peak}}{2} - C_{dc} V_{dc} \frac{d\overline{V_{dc}}}{dt} \tag{10}$$

Now by comparing the instantaneous ac output power in (5) and inverter output power as in (10), we will get,

$$\frac{d\overline{V_{dc}}}{dt} = \frac{V_{peak}I_{peak}}{2C_{dc}V_{dc}}cos(2\omega_g t\ ) \qquad \frac{d\overline{V_{dc}}}{dt} = \frac{S}{C_{dc}V_{dc}}cos(2\omega_g t\ ) \tag{11}$$

As $S = \frac{V_{peak}}{\sqrt{2}} \mathrm{x} \frac{I_{peak}}{\sqrt{2}} = V_{rms}I_{rms}$

Now by integrating (11) we will get,

$$C_{dc} = \frac{S}{2\omega_g V_{dc}\overline{V_{dc}}}sin(2\omega_g t) \tag{12}$$

Equation (12) reveals that the voltage reaches its maximum value at time$\omega_g t = \pi/4$, therefore (12) yield a dc-link capacitance size as,

$$C_{dc} = \frac{S}{2\omega_g V_{dc}\overline{V_{dc}}} \tag{13}$$

Where $C_{dc}$the capacitance of dc-link capacitor in farad, S is the rated power of the inverter, V_{dc} is the dc input voltage and $\overline{V_{dc}}$ is maximum permissible voltage ripple.

Equation (13) shows that the capacitance of dc-link capacitor is inversely proportional to the nominal bus voltage and voltage ripple. Hence a greater dc bus voltage yields a smaller capacitance capacitor however a smaller capacitance increases its voltage ripple. An increased voltage ripple affects the maximum power point operation of the PV generator if it is not properly controlled. Typically the value of voltage ripple should be kept below 8.5% to get maximum output from PV generator[6,30]. Table 4 shows the size of dc-link capacitor at various ripple voltage i-e 3%, 5% and 8.5% respectively in terms of the rated KVA rating of the inverter and nominal input voltage.

Table 4. Dc-link capacitor size at various ripple voltages

Power rating (kVA)	Inverter input voltage (V)	**Ripple voltage (V)**	**Nominal frequency (Hz)**	**Dc-link capacitor size (μF)**
3	370	11.1 @ 3%	50	1163
3	370	18.5 @ 5%	50	698
3	370	31.45 @ 8.5%	50	410

Thus a capacitor of $410\mu F$ is needed to be connected in parallel with a 3kVA inverter having a dc input voltage of 370V and maintaining a voltage ripple under 8.5%.

3 Conclusion

The size of dc-link capacitor based on input dc voltage and maximum allowable voltage ripple is derived in this study. It is seen that the capacitance will decrease with the increase in dc input voltage which increases the voltage ripple. Therefore, a suitable dc-link capacitor size should be chosen to restrict the voltage ripple with in a permissible limit and to ensure a better and reliable system performance and to achieve high power density of the system. Also a $410\mu F$ capacitor size is calculated for a grid connected inverter chosen in our research work. Also the types of capacitors used as dc-link are discussed in the study with their merits and demerits.

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