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# Connecting Wind Turbine Generator to Distribution Power Grid—A Preload Flow Calculation Stage

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**Abstract:** A distribution grid is generally characterized by a high R/X (resistance/reactance) ratio and it is radial in nature. By design, a distribution grid system is not an active network, and it is normally designed in such a way that power flows from transmission system via distribution system to consumers. But in a situation when wind turbines are connected to the distribution grid, the power source will change from one source to two sources, in this case, network is said to be active. This may probably have an impact on the distribution grid to whenever the wind turbine is connected. The best way to know the impact of wind turbine on the distribution grid in question is by carrying out load flow analysis on that system with and without the connection of wind turbines. Two major fundamental calculations: the steady-state voltage variation at the PCC (point of common coupling) and the calculation of short-circuit power of the grid system at the POC (point of connection) are necessary before carrying out the load flow study on the distribution grid. This paper, therefore, considers these pre-load flow calculations that are necessary before carrying out load flow study on the test distribution grid. These calculations are carried out on a test distribution system.

**Key words:** Distribution grid, power quality, wind turbine generator, load flow.

## 1. Introduction

Wind generation has been described to be one of the mature and cost effective resources among different renewable energy technologies [1]. Wind is a typical example of a stochastic variable, because of this stochastic nature; wind energy cannot be controlled, but can be managed [2]. The power quality and/or stability of the grid to which the wind turbines will be connected may be affected due to the random nature of the wind and the characteristics of the wind generators. It is, therefore, important to predict the impact of the wind turbines on the electric grid before the turbines are installed or connected.

Carrying out load flow analysis at the distribution level would not have been necessary if not because of the recent development in the distribution automation which includes using real-time application programs like SCADA (supervisory control and data acquisition) systems and installation of distributed generations (like wind turbine generators). This development brings about the issue of load flow study to be carried out in the distribution system [3].

The reason for this is that distribution grid system is generally designed to be passive network, i.e., it is made to deliver the power from the transmission system to consumers. It should be noted that real and reactive powers generally flow towards the edge of the system and in the direction of the voltage gradient (unidirectional power flow). In a situation where a wind turbine generator is connected to the distribution system, the power supply to that system is no more from one source, i.e., the source of conventional power, and the distribution network is converted from passive network to an active network [4, 5].

Before carrying out the above mentioned load flow study, two major calculations must be carried out in

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order to predict the state or condition of the distribution system, i.e., is it weak or strong enough to accommodate the new source of power (wind generator)? These two calculations are the steady-state voltage variation at the PCC (point of common coupling) [6] and the calculation of short-circuit power of the grid system at the POC (point of connection). Section 2 describes the sizing of the wind turbine to be connected to the grid. In Sections 3 and 4, the calculation stages before carrying out load flow analysis on the test system will be discussed and Section 5 concludes the paper.

## 2. Sizing the Wind Turbine to be Connected to the Grid

The size or rating of the wind turbine to be connected to the grid must be known before carrying out the calculation. According to Ref. [7], for a wind power source to be connected to the low voltage (i.e., via a transformer with a voltage ratio of 575:11,000) the total rated power of the wind generators to be so connected should not exceed 10% of the distribution transformer rated power.

In this paper, the wind turbines that are connected to the test distribution grid were chosen based on the above stated facts.

Each of the four step-up transformers T1, T2, T3, T4 (11-kV/33-kV) within the test system is rated 15 MVA at an assumed power factor of 1.0 lagging.

Therefore, 10% of 15 MVA = 1,500,000 VA = 1.5 MVA. This means that the maximum capacity of a wind turbine that can be connected to each bus of the existing grid should not be more than 1.5 MW. Four buses are considered for the connection of wind turbine in the test distribution system. A total of 6-MW wind turbine is connected to the test distribution grid. The simplified one-line diagram of the test system used in this paper is shown in Fig. 1.

The size of the wind power that will be connected to the existing distribution system will depend on the voltage level of that system and the short-circuit ratio of the grid.

## 3. Calculation Stages before Carrying out Load Flow Analysis on the Test System

It is worth mentioning here that there are two calculations to be done on the existing test power

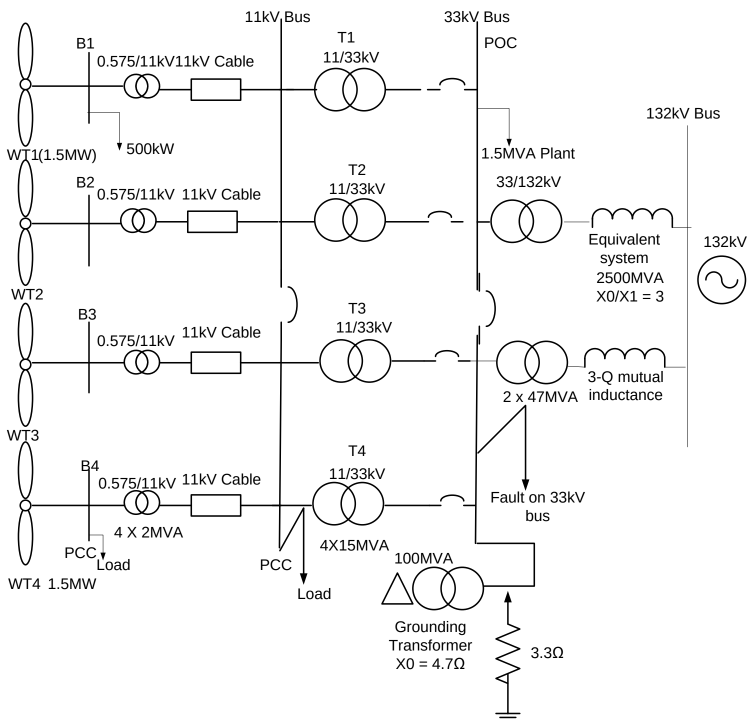


**Fig. 1 Simplified one-line diagram of the test system.**

system before finally carrying out a load flow analysis on the said distribution system. The first is the determination of the slow voltage variation at the PCC and the second is the calculation of short-circuit power of the test system at the POC. These calculations are necessary in order to know if the test system is weak or strong and to be sure that the grid can accommodate the new generation.

*3.1 Determination of Slow Voltage Variations*

The maximum steady-state voltage change denoted by $\epsilon$ (%) at the PCC can be evaluated using a simplified relation [8] given as:

$$\epsilon(\%) \cong \frac{100}{U_n^2}(R_k P_n + X_k Q_n) \leq 2\% \qquad (1)$$

where, $P_n$ and $Q_n$ are the wind turbine generator rated (or maximum continuous) active and reactive powers, respectively. $U_n$ is the nominal voltage of the network at PCC and $R_k$ and $X_k$ are respectively the resistive and reactive components of the short-circuit impedance at PCC.

Eq. (1), in practical situations, will yield a percentage voltage increase due to the active power flow on the resistive part of the network impedance, which may be very significant in the case of the weak grids. For this reason and according to Ref. [8], slightly inductive power factor values are usually preferred ($Q_n < 0$). The parameters of 11-kV, 3-core cable (i.e., $R_k$ = 0.411 Ω/km and $X_k$ = 0.107 Ω/km) used to connect the wind turbine to the 11-kV bus are as shown in Table 1.

The wind turbine generator's active and reactive powers are 6 MW and -2 MVAR, respectively. The active power of the generator is the wind power capacity that will be connected to the grid.

Putting all these values into Eq. (1) yields 1.86% which is less than the specified limit of 2%. This means that the voltage at the PCC is within permissible limit when 6-MW wind turbine generator is connected to the test distribution network. Voltage variations are the aggregate effect of generating facilities and network load, a more detailed evaluation that involves load flow calculation will be necessary at this point, but before this, the short-circuit power of the test distribution system needs to be calculated.

## 4. Short-Circuit Power of the Test System

Short-circuit power is the maximum power that a network can provide to an installation during a fault. It is also a normal parameter for measuring the strength of a busbar in a typical AC network. It is expressed either in MVA or in effective KA for a given service voltage. Short-circuit power (depends on the network configuration and the impedance of its components such as lines, cables, transformers, etc. [10].

This is given in Eq. (2) as:

$$SC_{MVA} = I_{fault} X V_{AC} = \frac{V_A^2 C}{Z_{th}} \qquad (2)$$

where, $SC_{MVA}$ is short-circuit power of the test system, $I_{fault}$, $V_{AC}$ and $Z_{th}$ are respectively the fault current (in amps), the bus nominal voltage (in volts) and the thevenin's impedance (in ohms) seen from the bus. It is, therefore, necessary (according to IEEE recommendation) to find out if the AC grid is strong enough to receive the power from the wind generators connected to it. This is because short-circuit parameter is frequently the main limitation to wind power penetration into grid.

The short-circuit power is always calculated at the POC. In this test system, a 33-kV bus voltage is used. This is because it is the bus voltage at the point of connection.

In the work reported here, the impedance with the highest resistance to reactance ratio (cable impedance) was used for the calculation of the short-circuit power. This is because the cable is used to connect the test distribution network to the POC, i.e.,

$R_k$ = 0.4110 and $X_k$ = j0.1070 i.e.,

$Z_{th}$ = 0.4110 + j0.1070

$|Z_{th}|$ = 0.425

**Table 1 Parameter of 11-kV, XLPE (Cross Linked Polyethlene), 3-core, 3-phase, and 50-Hz power cable used [9].**

| Resistance in Ω/km | Inductive reactance (X) Ω/km | Cable type | No. of cables in parallel | Conductor size ($mm^2$) | Voltage kV | Rating (amp) |
|---|---|---|---|---|---|---|
| 0.411 | 0.107 | Cu/XLPE 3 ×1 core | 4 | 95 | 11 | 207 |

Therefore, putting all the known values into Eq. (2) gives:

$$SC_{MVA} = \frac{33,000^2}{0.425} = 2,562.4 \text{ MVA}$$

The SCR (short-circuit ratio) of the test distribution system is defined as the ratio of the short-circuit power to the wind turbine rated power. This is expressed as:

$$SCR = \frac{SC_{MVA}}{P} = \frac{V_{AC}^2}{Z_{th} \times P} \quad (3)$$

Therefore, with the information given above, we have:

$$SCR = \frac{SC_{MVA}}{P} = \frac{2,564 \times 10^6}{6 \times 10^6} = 427$$

It is important to state here that the wind capacity, *P*, of the test system is 6 MW wind generator.

If the SCR is greater than 200 according to Ref. [11], connecting a wind turbine to an existing power distribution system will be stable, i.e., it will be free from voltage flickers, harmonics and that the voltage regulation will be within permissible limit.

Since the calculated SCR as shown above is greater than 200, it means that the grid is strong enough to receive the power from the wind generator.

It is obvious from Eq. (3) that the SCR is directly proportional to the square of the voltage at assumed infinite bus and inversely proportional to the impedance between source and load. It also means that if the impedance is larger, fault level ($SC_{MVA}$) will be less, giving a lower SCR. Consequently, the grid will be considered weaker.

This will restrict the possible connection/installation of the wind turbines to the distribution system.

Another author in Ref. [12] also stated that the short-circuit power at the point of connection to the medium voltage network (33-kV) must be at least 50 times the apparent rated power of the wind power installation.

In the present case, this is as calculated above, i.e.,

$$SC_{MVA} = 2,562.4 \text{ MVA}$$

This shows that 50 multiply by 6 MW of wind installed on the system is 300 MVA, but the calculated $SC_{MVA}$ is 2,562.4 MVA which is by far greater than 300 MVA.

This confirms that the test distribution network can accommodate the new generation from the wind.

## 5. Conclusion

The pre-load flow calculations carried out on the test distribution system in Fig. 1 shows that the grid system voltage at the PCC is within the permissible limit when the 6-MW wind turbine generator is connected to the test distribution network. Also, the SCR of the grid with respect to the wind power can be seen from the calculation to be far greater than 200. Hence, it can be concluded that the test distribution system is healthy or strong enough to accommodate the wind power. However, the knowledge of the grid parameters alone is not usually sufficient to relate the interaction between the grid and the wind turbine generator during steady-state operation. The only tool that can handle this is the load flow analysis. The load flow study needs to be carried out on the test distribution system with and without the connection of wind turbines to actually see the reaction of the existing distribution grid to the incoming wind power.

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