Controlling Voltage Levels of Distribution Network-Radial Feeder after Connecting Wind Turbines to the Network

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Abstract:

Several factors in power generation and supply need to be taken into account such as shortages of energy supply, system stability, and energy quality and system disruption due to network losses, industrial development and population expansion. The addition of wind turbines to the distribution network is of great benefit in providing additional power and solving these problems, but this addition is accompanied by the problem of low voltage network. This research found optimal solutions to the problem of low voltage distribution network after connecting wind turbines. The main idea of this paper is to optimize the low-voltage problem as a result of connecting the wind turbines to the "far end" of the radial feeder for a distribution network and to obtain a voltage level within an acceptable and stable range. The problem of low voltage solved by using the load-drop compensation, capacitor-bank and “doubly-fed” induction generators. The results of this study were based on the operation of the entire design of the simulation system which would be compatible with the reality of the energy flow of all network components by using the PSCAD program. The present analysis program revealed an optimum solution for the low voltage profile of the distribution network after connecting the wind turbine.

Keywords: Distributed Generation; Wind Turbine; Voltage Profile, Line-Drop Compensation; and Radial Feeder.

الخلاصه

عدة عوامل يجب ان تأخذ بنظر الاعتبار عند توليد الطاقة الكهربائية مثل، نقص إمدادات الطاقة، استقرار النظام، نوعية الطاقة، وتعطل النظام بسبب خسائر الشبكة نتيجة التنمية الصناعية والتوسع السكاني. اضافة توربينات الرياح الى شبكة التوزيع تساهم في توفير طاقة إضافية وحل هذه المشاكل، ولكن هذه الإضافة ترافقها مشكلة الجهد المنخفض للشبكة. الفكرة الرئيسية لهذا البحث هو الحفاظ على مستوى فولتية لوحدة تغذية شعاعية لشبكة توزيع ضمن نطاق مقبول وثابت عند إدخال توربينات الرياح إلى وحدة التغذية في "الطرف البعيد". هذا البحث يبحث في ايجاد الحل الامثل لمشكلة الجهد المنخفض لشبكة التوزيع بعد ربط توربينات الرياح. نتائج هذه الدراسة اعتمدت البرنامج "PSCAD" لتشغيل تصميم كامل لنظام المحاكاة التي ستكون متوافقة مع واقع تدفق الطاقة لجميع مكونات الشبكة . كشف برنامج التحليل الحالي عن الحل الأمثل لملف الجهد المنخفض لشبكة التوزيع بعد توصيل توربينات الرياح.

الكلمات المفتاحية :- المولدات الموزعة، توربين رياح، قيمة الفولتية ، معوض مفاقيد الخط والمغذي الشعاعي .

1. Introduction

The electrical power system is divided into three different sections; power “generation”, “transmission”and“distribution”. The most important section is the distribution network due to the large network complexities such as increasing energy demand, volatility in the peak load and voltage regulations. One of the best solutions to the above problems is to insert distributed generation to the grid. All power generators that do not use fuel in their operations and located near to the consumption areas are called distributed generation (DG). The utilization of DG is going to increment in the upwards and coming future as they have a great deal of positive effects on power generation, for example, perfect size, losses decrease and voltage support (Alexis, 2016). Moreover, as of late, distributed generation has picked up a great deal of momentum because of market deregulation, ecological effect concerns, and improvement of new technologies to power generation and need of increasing the dependability quality of industrial plants. By one means or another, DG has some negative effects on, for example, voltage regulation, harmonic distortion and the protection system. The investigation was centered around deciding the effect of DGs on electric power system (EPS) performance. One of these DGs is the wind turbines (WTs) which are adopted in this study. These days, wind turbines are playing a big role in the production of energy because of their great benefits to the environment and non-use of traditional sources of combustion (Alexis, 2016). Wind turbines have been playing a key role in providing the real power to the consumer locally, which means no need for transmission lines anymore.

The connection of wind turbines to the distribution networks, especially with radial feeders, leads to low network's voltage problem. This problem is due to the consuming of the reactive power by WTs, which is compensated by diesel generators at the beginning of the feeder, resulting in a high drop in the voltage of the feeder (Ding and Girgis, 2000). One of the worst distribution network problems is the low level of voltages at consumers connecting points of the radial feeder. In other words, the big challenge of the distribution system is the regulation of voltages on loads of radial feeder in the remote areas (Gõnen *et.al.*, 2000). Many methods and devices were used to address this problem in the distribution network. The most effective tools and equipment used for radial feeders are the line drop-compensator and a capacitor bank equipped in parallel with the feeder. Also, the use of a "double-fed" induction generator instead of direct-coupled induction generator in WTs (Del Monaco *et.al.*,2001).The work principle of the "LDC" provides that the change in the output voltage of the transformer depend on the amount of current passing through the feeder, the more the current pass through the feeder, the more the voltage drop on it and "vice-versa". The transformer thus changes the terminal voltage to re-adjust the voltage to a specific level. Connecting the capacitor in parallel with the radial feeder is in order to raise the feeder voltage at the point of contact because the capacitor injects the reactive power in the grid (Joon and Jae, 2001)."Doubly-fed" induction generators can preserve the "amplitude" and "frequency" of their output-voltages at a fixed value. Due to this characteristic, they can stay synchronized when connected directly to the power grid all the time. As well as, these generators are able to keep the power factor equal to "one"(Del Monaco *et.al.*, 2001). There is a significant overlap between the distribution network technologies and wind turbines, resulting in significant disturbances that affect the quality of the power and level of the voltage due to the addition of wind turbines to the grid(Mohsen and Hosein ,2017; Rather and Flynn, 2017).

To bolster this contention, simulation has been accomplished on PSCAD, where comes about demonstrates the impact of WT on the voltage regulation. The PSCAD Power Engineering-Programming is a suite of uses made out of a system editorial manager, examination modules and client adaptable model libraries from which you can get the most effective solutions. The PSCAD programming plays out a few kinds of investigation on adjusted or uneven three-stage, two-stage and single-stage systems that are worked in outspread, circled or radial arrangements of network feeders. In this study, the PSCAD was utilized to solve the low voltage problem due to the connection of WTs to the distribution network-radial feeder. The solutions are to boost and to stabilize the voltage profile of the radial feeder after connecting the wind turbines.

2. System Configuration

2.1. The System Model

The simulation model for this work has been simulated in the "PSCAD" software. For the simplicity, the modeling system represented in **Fig. 1** shows the entire model. In the model, all the protection devices have been taken in consideration.

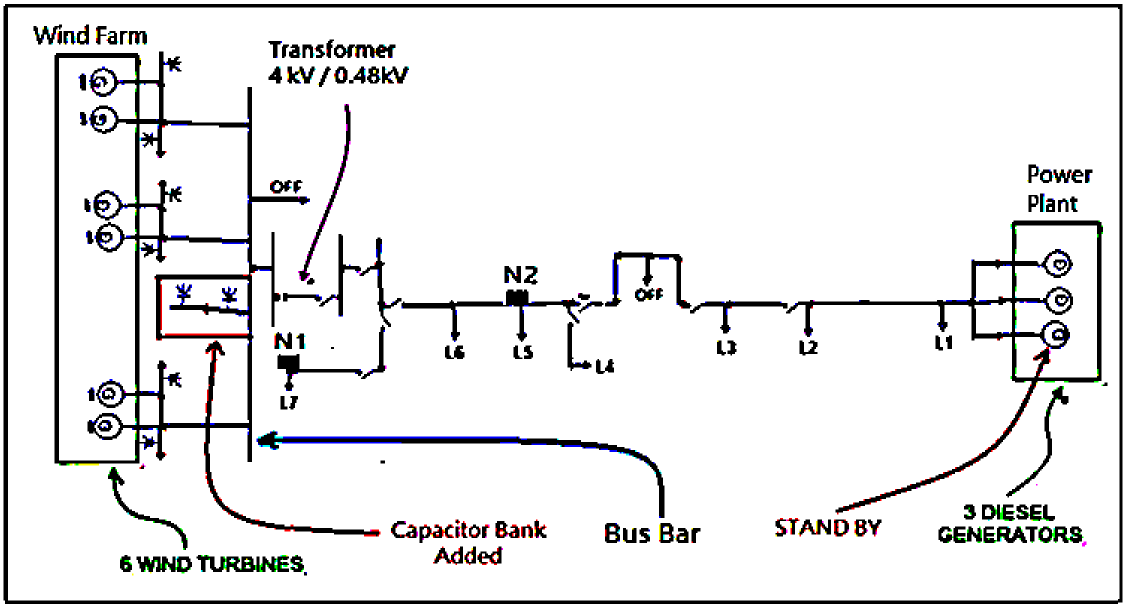

Fig. 1: The designed of system model in this study

The simulation model used in this study including the following details:

The generators of the power plant are diesel-units and synchronous types. They are three, (1000 kVA) each, supplied the radial feeder. Two generators are able to cover the full load of the network and the third generator is kept ready for emergency "Stand-by". The diesel-units on duty, one operates as a "swing-bus" with 1.0 p.u. the level of the voltage at the terminal and the other works as a voltage regulator to keep the terminal voltage equal to 1.0 p.u. Each one of these generators supplies the network by 466 kW. The operating capacity of these diesel-generators is limited by (30%). The benefit of these diesel-generators is that their terminal-voltage can be controlled. The Load Drop-Compensation ("LDC") was used with these generators to compensate the drop voltages on the distribution network.

It was a four mile length, and 4 kV type. This feeder supplies many different loads branches (L1 to L7), their summation equals to 1.072 MVA which distributed randomly over the feeder with different values of the power factor at a rate of 86% as indicated in **Table 1**.

Table 1. Loads and power factors % for the simulation model.

Loads	MVA	Power Factor %
L1	0.468	0.90
L2	0.196	0.81
L3	0.013	0.94
L4	0.147	0.82
L5	0.105	0.80
L6	0.105	0.84
L7	0.038	0.91

It is a group of six wind turbines, asynchronous generator types, which are installed at the far end of the radial feeder. WTs drive 470 V induction-generators which are direct-coupled to the distribution network. The generating capacity of each wind turbine is 45 kVA at 0.8 power factor. The rate of the permeation of WTs in the network was with full capacity. In addition, a capacitor bank of 360 kVar is equipped in parallel with WTs.

2.2. The Simulation Process

The simulation system is identical to the study of the power flow. Therefore, the procedure of this simulation has many steps to follow such as monitoring and controlling the magnitudes of voltage-profile to include the entire feeder**.** Therefore, the simulation was run once without WTs and repeated many times with WTs. Also, the load of the feeder is considered to be at maximum. All results of the above strategies are measured at (**N1** and **N2**) and plotted by using (PSCAD) software.

3. The Results and Discussion

3.1. Without Wind Turbines

The simulation system was run before wind turbines were introduced to the grid. The curves of the results in **Fig. 2** show that the levels of the radial feeder voltage vary in amounts along the feeder. These amounts are shown to decrease as the distance from the generating station increases. The results proved that the network has a low voltage level issue, especially at the “far end” of the feeder.

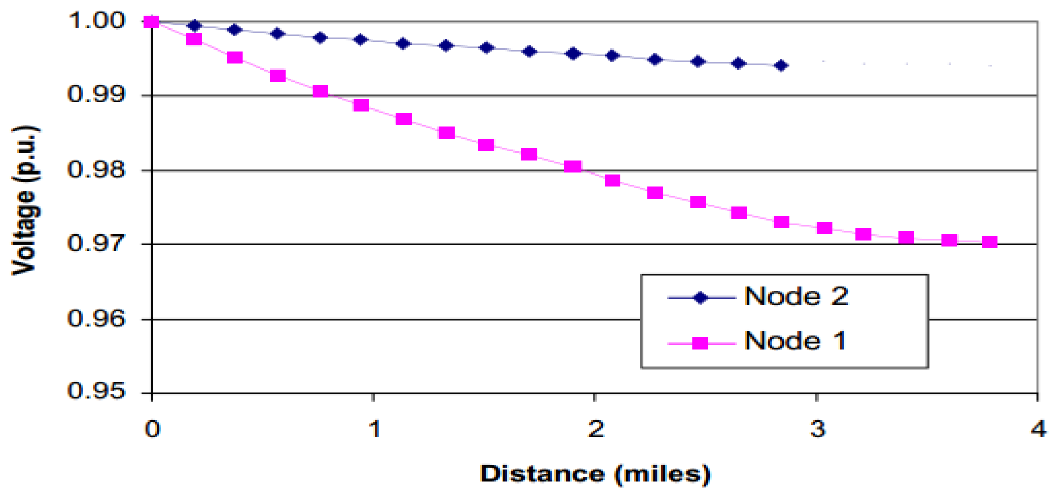

Fig. 2: The voltage profile of the feeder without WTs.

3.2. With Wind Turbines

In fact, connecting WTs to the distribution grid results in an imbalance of energy consumption. Therefore, this condition should be taken into account. The simulation model run with connecting “WTs” to the network at the ‘far end’ from the substation.

The results in **Fig. 3** show a severe low voltage issue along the most parts of the feeder due to the consuming of a reactive power by WTs, which caused a huge drop voltage especially at the remote end of the feeder.

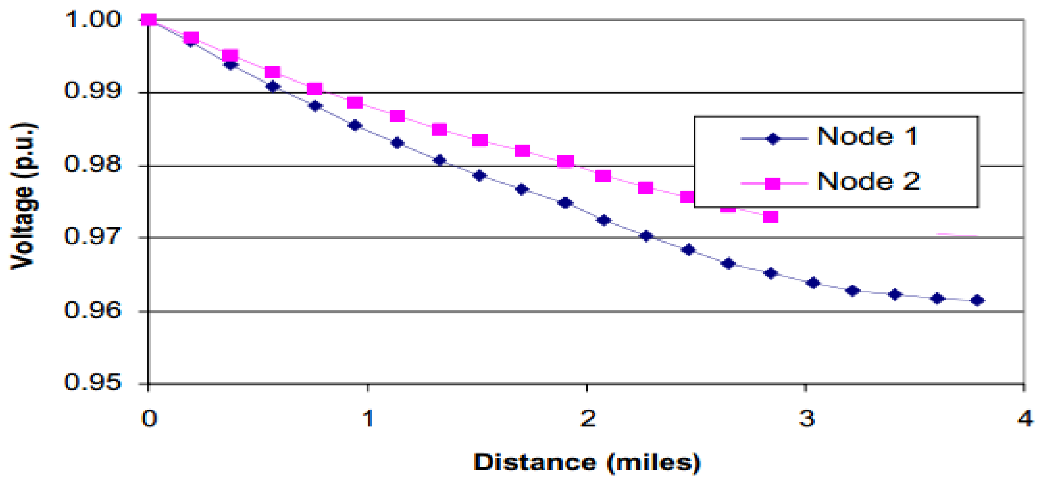

Fig. 3: The voltage profile of the feeder with WTs.

The best three solutions to this low voltage issue are as follows:

1. Line-Drop Compensation

The terminal voltage level of the substation must be increased to 1.05 p.u. by using the "LDC". The setting for LDC has two compensating conditions resistive and reactive. In this situation, the LDC should be set in a reactive mode in order to cover the reactive power consume by WTs. This solution is really a useful solution as indicated in **Fig. 4**, the LDC compensates some of the reactive power and raises the network voltage, but the voltage level remains undesirable at the "WTs-Bus".

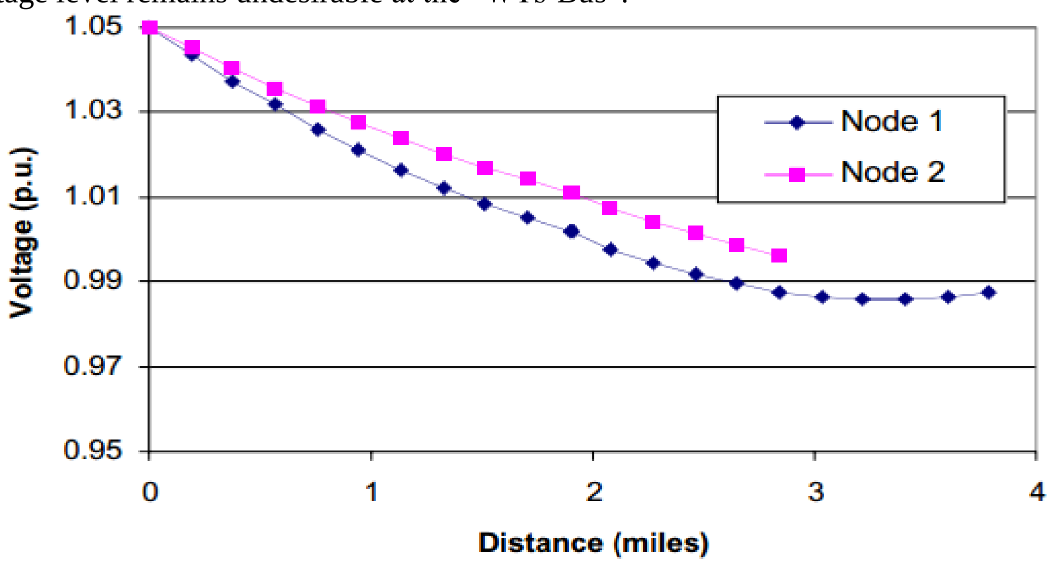

Fig. 4: The voltage profile of the feeder after increasing the voltage of the terminals of the diesel-units to 1.05 p.u.

2. Capacitor Bank

The system operated again with a capacitor bank of 30 kVar which is equipped in parallel with each WT. This shunt capacitor will switch on only when another WT with same characteristics is operated. In this case, the local capacitor-banks are switched-on in order to increase the (p.f) from 0.8 to 0.9 pu which supports the field of the generator. While the diesel-generators are still supplying the network with 0.33 MW and the voltage at the their terminals is 1.00 p.u. **Fig.5**. clarifies that this solution is an optimal one to boost the voltage level of the radial feeder.

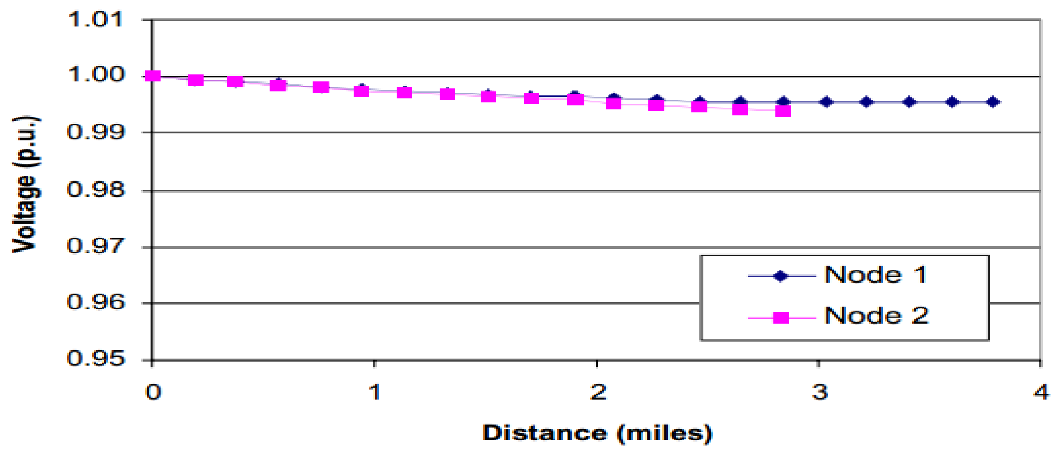

Fig. 5: The voltage profile of the feeder after adding the capacitor-bank

3. "Doubly-fed" type of induction generators

The system was run again by using double-fed type of induction generators in WTs that are being characterized by the possibility of controlling their terminal voltage instead of directly coupling induction generator. As a result, this type shows a great success in raising the level of the voltage of the network as indicated in **Fig. 6**.

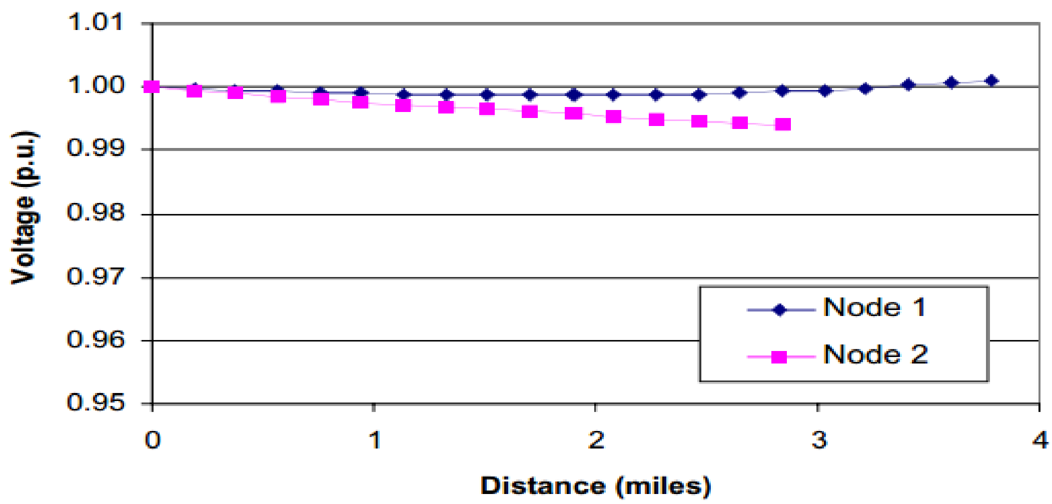

Fig. 6: The voltage profile of the feeder with using of "Doubly-fed" type of induction generators in WTs.

4. Conclusions

It is a challenge to insert WTs to a radial-feeder of a distribution network for causing a low voltage issue on the majority parts of that feeder. This study is ended up with optimal solutions to this issue and it can be summarized as follows:

- Adjusting the LDC setting at the power plant to compensate the drop voltage on the network.
- Using capacitor bank equipped in parallel with WTs to rise the power factor.
- Maintaining the voltage level of the generator terminal of the wind turbine by using the "doubly-fed" induction generators instead of "direct-coupled" induction generators. From this study, it can conclude that connecting WTs to the distribution network can inject more power to the network, which is an excellent job to compensate the load demand.

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