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# Enhancing the Integration of Renewable Energy Sources in Baghdad Power Grid through Smart Link

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**Abstract**

This paper mainly discusses effective method of connecting double fed induction generator wind turbine into power grid through Insulated Gate Bipolar transistor (IGBT). The work can be divided generally into two major groups. Firstly 4 different procedures for connecting double fed induction generator wind turbine into grid has been evaluated based on grid voltage profile and power losses. Voltage profile and losses of every method in calculated through forward backward sweep load flow method. Wind turbine is connected into transmission system and distribution system both with back to back converter and without back to back converter. From aforementioned four method of connecting wind turbine into gird optimum method is selected for further analysis.

**Keywords**: Iraq, Smart Link (BTB Converter), Renewable energy, Control Power Flow, Matlab.

## 1. Introduction

The global energy consumption is rising and an increasing attention is being paid to alternative methods of electricity generation. The very low environmental impact of the renewable energies makes them a very attractive solution for a growing demand. In this trend towards the diversification of the energy market, wind power is probably the most promising sustainable energy source. The progress of wind power in recent years has exceeded all expectations, with Europe leading the global market [1]. Recent progress in wind technology has led to cost reduction to levels comparable, in many cases, with conventional methods of electricity generation.

Power electronics are nowadays used to efficiently interface renewable energy systems to the grid [2]. They are playing a very important role in modern wind energy conversion system (WECS) especially for MW-size wind turbines (WT) concentrated in large wind farms. Control of WECSs, performed by means of power electronics; allow the fulfillment of grid requirements, a better use of the turbine capacity and the alleviation of aerodynamic and mechanical loads that reduce the lifetime of installation [1]. Furthermore, with WECSs approaching the output rating of conventional power plants, control of the power quality is required to reduce the adverse effects of their integration into the grid. Even though active control has an immediate impact on the cost of wind energy, it leads to high performance that is essential to enhance the competitiveness of wind technology.

### 1.1 Wind turbine

The wind turbine converts the kinetic energy from the wind into mechanical energy. To represent the wind turbine a model found in the SimPower Systems library in MATLAB®/Simulink® is used. The output power of the turbine, Pm, is given in (1).

$$\boldsymbol{P_m = C_p(\lambda, \beta)\frac{\rho A}{2}V_{wind}^3} \quad (1)$$

Where;

$C_p$ is the performance coefficient of the turbine.

ρ is the air density.

A is the rotor area.

$v_{wind}$ is the wind speed.

$C_p$ is given in (2) [18].

$$C_p(\lambda, \beta) = 0.5175 * \left(\frac{116}{\lambda_l} - 0.4\beta - 5\right) * e^{\frac{-2l}{\lambda_l}} + 0.0068 * \lambda \quad (2a)$$

$$\frac{1}{\lambda_l} = \frac{1}{\lambda + 0.08\,\beta} - \frac{0.035}{\beta^3 + 1} \quad (2b)$$

Where:

β is the pitch angle of the rotor blades in degrease

λ is the ratio of the rotor tip speed to wind speed.

From (1) it can be shown that the power from the wind turbine is proportional to Cp. (Fig. 1) illustrates Cp as a function of the tip speed ratio λ for different values of pitch angle β. Cpmax=0.4667 is found for β=0° and λ=8.1. This value for λ is called λnom and is used in the control of the wind turbine as this is the tip speed ratio that gives the highest output power for any wind speed as long as β=0°. The pitch angle is used to limit the output power when the wind speed exceeds nominal speed.

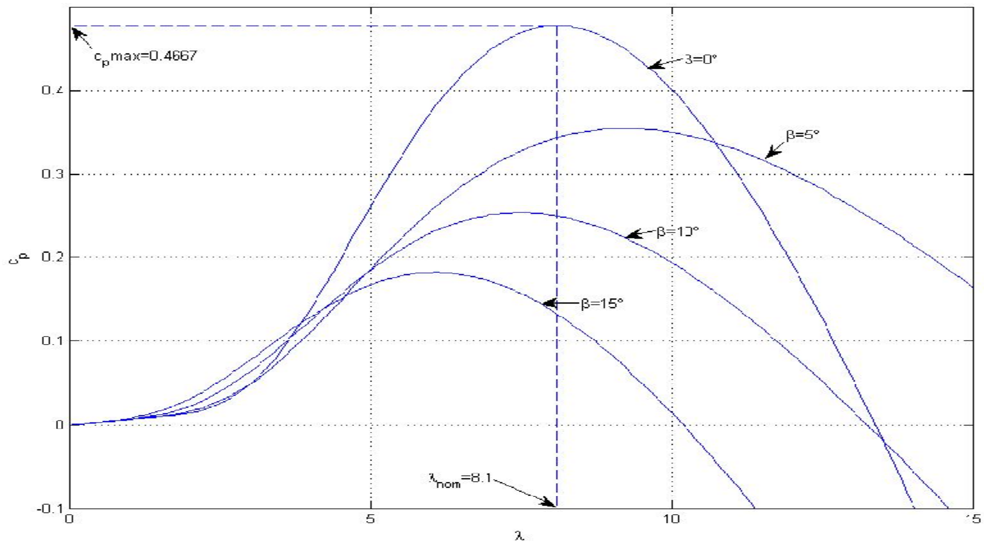



**Fig. 1**: Cp–λ characteristics for different values of pitch angle β.

The mechanical output power as a function of turbine speed for different wind speeds and pitch angle β=0 is illustrated in (Fig. 2). It can be noticed that for every wind speed there is an optimal turbine speed that produces the maximum amount of power. By setting λ=λopt the optimal turbine speed is proportional to the wind speed as shown in (2).

$$\omega_{ref} = \frac{\lambda_{opt} V_{wind}}{r_{blades}} \qquad (3)$$

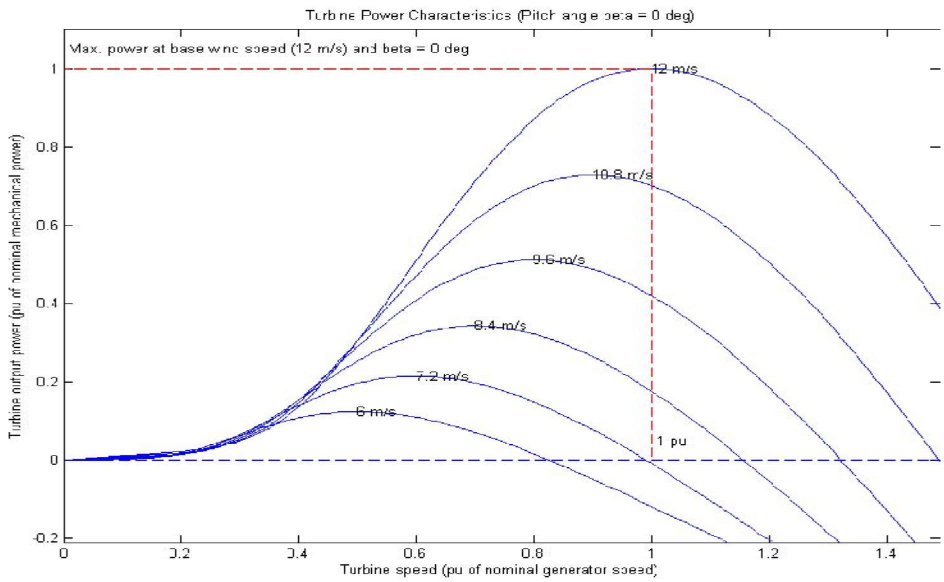



**Fig. 2**: Output power of the wind turbine as a function of turbines speed and speed

**1.2 Load Flow Analysis**

The load flow of a single source network can be solved iteratively from two sets of recursive equations. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node. These recursive equations are derived as follows. The (Fig. 3) shows the representation of 2 nodes in a distribution line. Consider a branch ‘j’ is connected between the nodes ‘i’ and ‘i+1’.

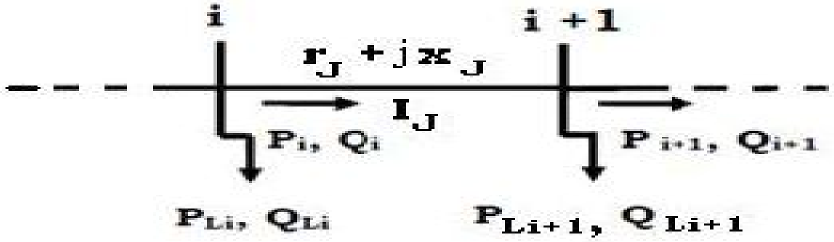



**Fig. 3**: Representation of two nodes in a distribution line.

The effective active ($P_i$) and reactive ($Q_i$) powers that of flowing through branch ‘j’ from node ‘i' to node ‘i+1’ can be calculated backwards from the last node and is given as in (4) & (5)

$$P_{i=}p_{i+1+}r_j\left(\frac{p'^2_{i+1+}Q'^2_{I+1}}{V^2_{i+1}}\right) \tag{4}$$

$$Q_{i=}Q_{i+1+}x_j\left(\frac{p'^2_{i+1+}Q'^2_{I+1}}{V^2_{i+1}}\right) \tag{5}$$

The voltage magnitude and angle at each node are calculated in forward direction. Then the current flowing through the branch ‘j’ having an impedance, $z_j = r_j + jx_j$ connected between ‘i’ and ‘i+1’is given as,

$$I_j = \left(\frac{V_i\delta_i - V_{i+1}\delta_{i+1}}{r_{j+}jx_j}\right) \tag{6}$$

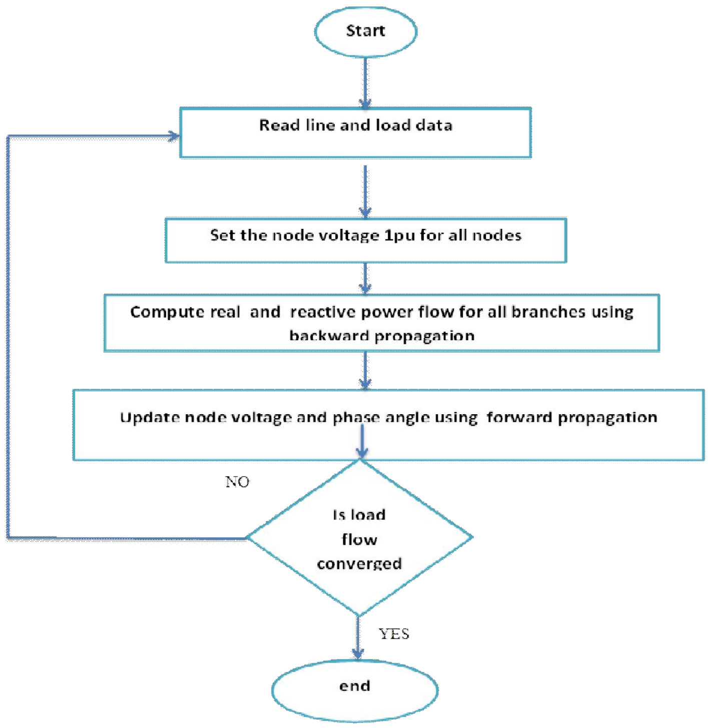
The real and reactive power losses of branch ‘j’ can be calculated as,

$$Ploss_{(j)} = r_j\left(\frac{p_i^2 + Q_i^2}{V_i^2}\right) \tag{7}$$

$$Qloss_{(j)} = x_j\left(\frac{p_i^2 + Q_i^2}{V_i^2}\right) \tag{8}$$

**Load flow by Algorithm for Load Flow Calculation**

- Step 1: Read distribution system line and load data. Assume initial node voltages are 1 pu and set ε =0.0001.
- Step 2: Start iteration count, IT =1
- Step 3: Initialize real power loss and reactive power loss vectors to zero.
- Step 4: Calculate the effective real and reactive power flow in each branch
- Step 5: Calculate node voltages, real and reactive power loss of each branch
- Step 6: Check for convergence i.e., ΔV max< ε in successive iterations. If it is converged go to next step otherwise increment iteration number and go to step 4.
- Step 7: Calculate the real and reactive power losses for all branches and also total real and reactive power loss using the MATLAB code.
- Step 8: stop.




Flow chart load flow (forward-backward)

## 2. Case Study

Baghdad city power supply is provided basically from six main substations 400/132kv, which in turn supply many substations of 132/33kv, (132/33/11kv) most of these 33/11kv substations are equipped with transformer of 31.5MVA.This works is based on small portion of Baghdad power grid and it is situated in south-east of the city as illustrated in (Fig. 5). The area is supplied with an 11 KV feeder from Al-Khalij substation. It is a radial distribution system with 14 buses, and total of 25 MVA load.

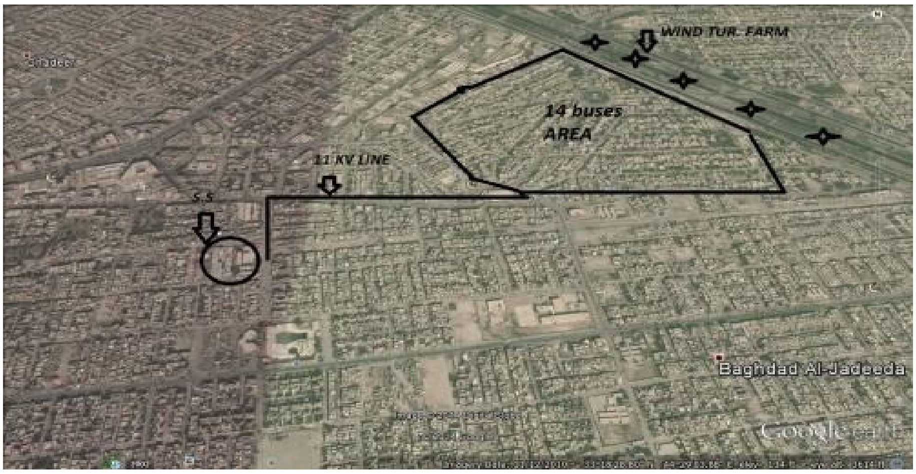



**Fig. 5**: The small area integration with wind turbine.

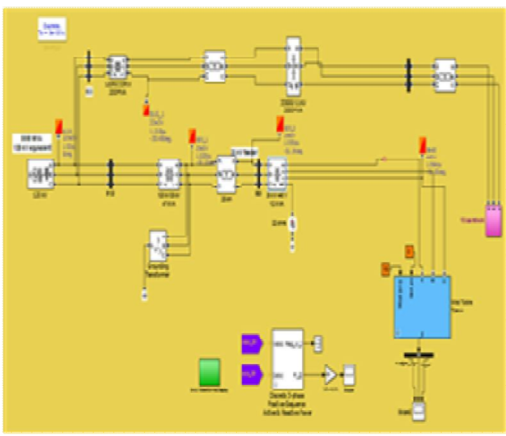
The main objective of this work is to evaluate effective method to penetrate a wind generation farm consists of 5 wind turbines with a capacity of 2 MVA each. It compares penetrating the wind farm in distribution as well as in transmission system.

The system has 14 buses, supplied with one 11 KV line (in this work it is taken care by a conventional energy source).

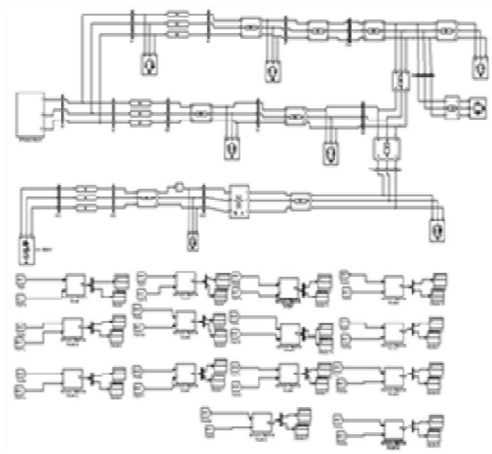
It is modeled into four different forms based of integrating wind turbine into the system:

1. Wind turbine is connected to distribution system without Smart DC-link(BTB)
2. Wind turbine is connected to distribution system with BTB Converters as DC-link
3. Wind turbine is connected to transmission system without Smart-DC-link(BTB)
4. Wind turbine is connected to transmission system with BTB Converters

WT Connected to Transmission without BTB Converter



WT Connected to Distribution system

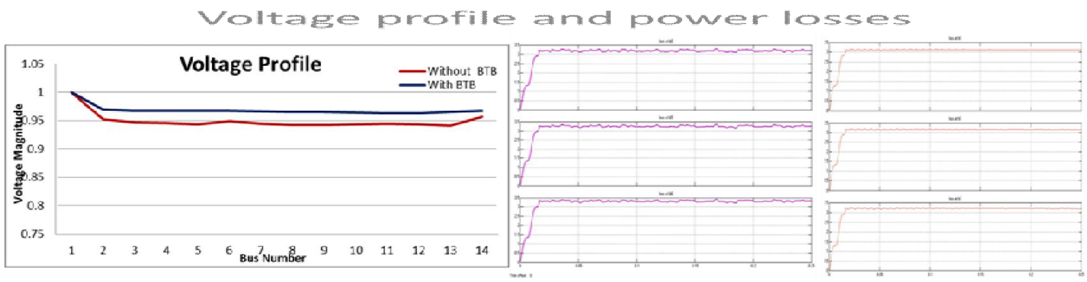


## 3. Results

For selecting best possible method of integrating wind turbine to system, they are compared based of losses of the system and voltage profile. Power flow analysis using backward forward sweep method is used to find power losses and voltage profile of the system.

- **Results of penetrating wind turbine into transmission system**

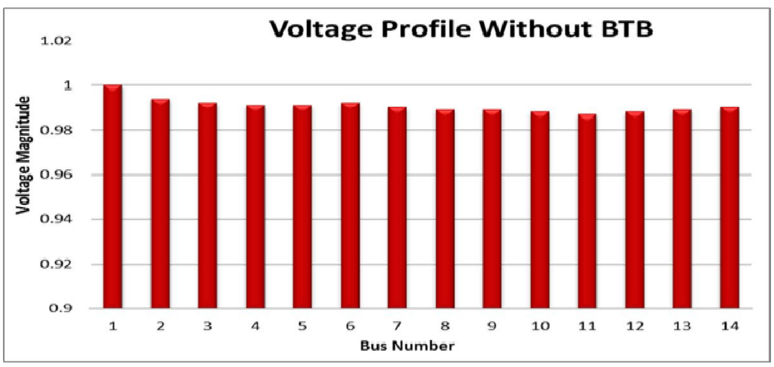
In this section result of two cases; wind turbine integrated to transmission system with and without back to back converters (smart-dc-link) is illustrated. Losses of the system for a load curve of 24 hours is calculated for both case and compared. Besides, voltage profile of a specific bus is compared for both cases. Results are illustrated in the following graphs.

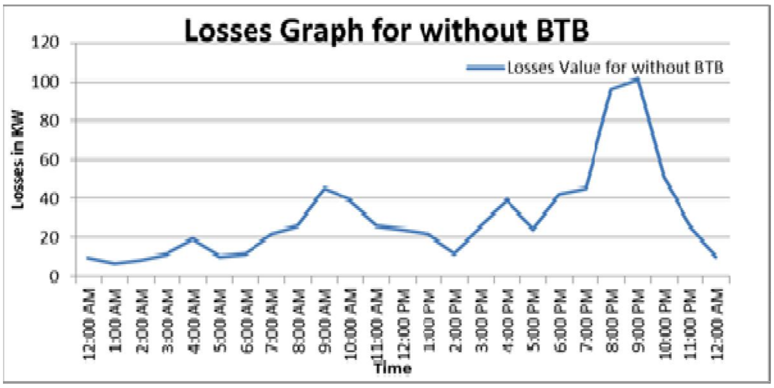



As the result of comparison shows losses of the system is less in case of integrating the wind farm to the system through back to back converter than connecting it directly. Differences in losses of power are approximately 10 % between them. Also, voltage profile in case of connecting through BTB improves along with minimizing voltage fluctuation and frequency fluctuation.

- **Results of penetrating wind turbine into distribution system**

In this section result of two cases; wind turbine integrated to distribution system with and without back to back converters (smart-dc-link) is illustrated. Losses of the system for a load curve of 24 hours is calculated for both case and compared. Besides, voltage profile of a specific bus is compared for both cases. Results are illustrated in the following.




Losses Graph for without BTB
Losses Value for without BTB
Losses in KW
Time
120
100
80
60
40
20
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
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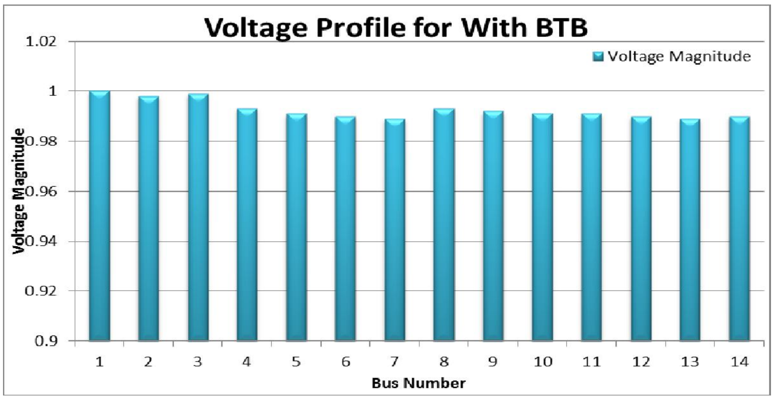
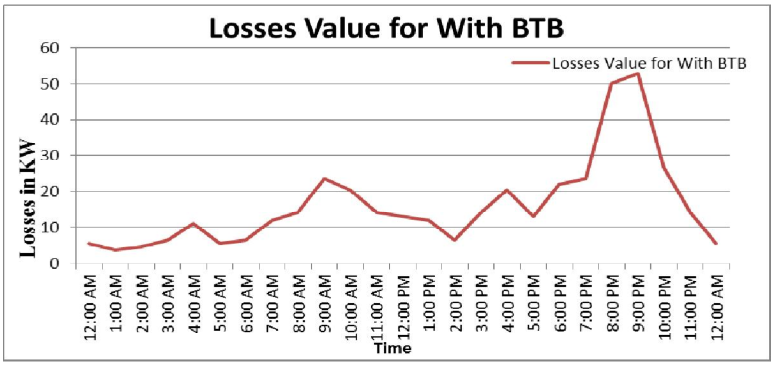
11:00 PM
12:00 AM


Voltage Profile for With BTB
Voltage Magnitude
Voltage Magnitude
Bus Number
1.02
1
0.98
0.96
0.94
0.92
0.9
1
2
3
4
5
6
7
8
9
10
11
12
13
14


Losses Value for With BTB
Losses Value for With BTB
Losses in KW
Time
60
50
40
30
20
10
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
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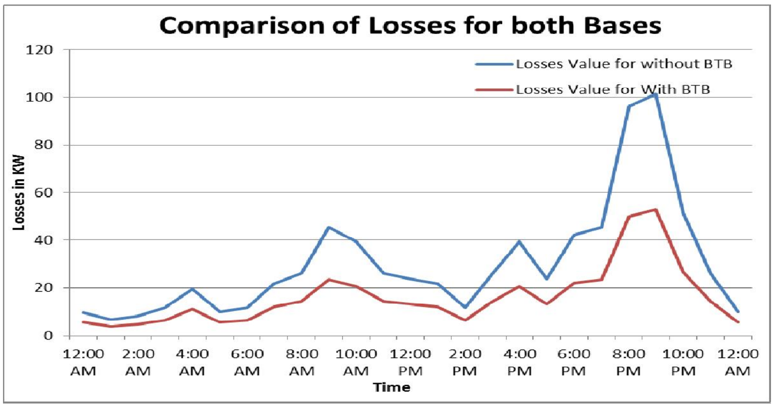
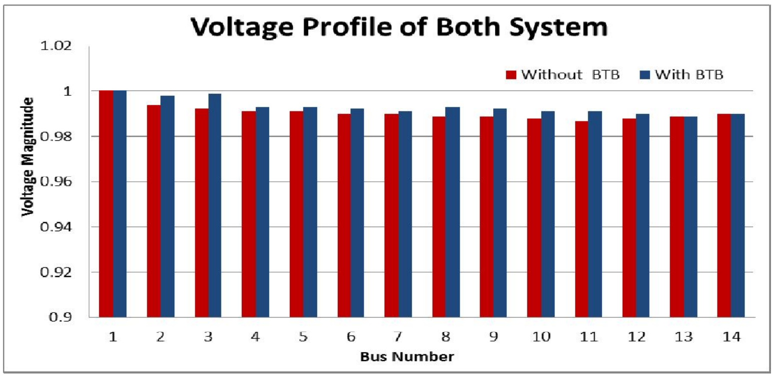
11:00 PM
12:00 AM


Comparison of Losses for both Bases
Losses Value for without BTB
Losses Value for With BTB
Losses in KW
Time
120
100
80
60
40
20
0
12:00 AM
2:00 AM
4:00 AM
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
8:00 PM
10:00 PM
12:00 AM




As the result of comparison shows losses of the system is less in case of integrating the wind farm to the system through back to back converter than connecting it directly. Differences in losses of power are approximately 40 % between them. Also, voltage profile in case of connecting through BTB improves along with minimizing voltage fluctuation and frequency fluctuation.

From above evaluation it is clear that best option for integrating wind farm to the selected power system is in distribution system with back to back converter. Thus this option is selected for further studies. In the following section economic assessment is presented for the selected option.

- **Economic assessment:**

Loss reduction clearly represents a benefit for utility; however, the use of a BTB converter involves an important investment that has to be justified. For this purpose, a rough economic study based on a simplified payback analysis is performed .the payback related to candidate investment can be defined as follows:

$$PB = IC/AI$$

Where:

PB is payback Ratio in years

IC is the investment cost

AI is the additional yearly incomes due to the investment.

(9)

(10)

Where:

$IC_{\circ}$ and $AI_{\circ}$ refer to the investment and annual incomes without BTB

$\Delta IC$ and $\Delta AI$ represent the increment of those values when BTB converter is installed Previous formula expressed as:

(11)

Where:
$S_{DG}$ corresponds to the initial DG installed power
$\Delta S_{DG}$ is the increment of installed power
$S_{DC}$ is the rated power of the smart link (BTB)
$PC_{DG}$ is the cost (euro/kVA)
$PC_{DC}$ is the smart link cost
$EC_{DG}$ is the DG energy price
T refers to equivalent hours of operating at rated power of DG

After some mathematical manipulations the equation can be simplified as:

$$PB=\frac{\text{investment cost}}{\text{additional incoming}} \tag{12}$$

Investment cost equals to cost of BTB converter and it has been estimated as 500 euros/kVA that includes VSCs, switchgears, measurement, control, and coupling transformers.

Additional incoming consists of:

$\Delta P$: Energy reducing of losses of the distribution system.

E: Energy price of the wind plants and it is 0.32 euros/kWh

T: Equivalent hours of operation at rated power of the DG.

In economic assessment in power system, it is said that the investment is economical if the benefit from applying these new technology pays prices of the technology in less than 5 years. for example if system only have 600 Kw power losses, payback period of implementing back to back converter is only 1.13 years. That means that this technology is very economical.

## 4. Conclusion

The piper main objective is to integrated wind farm energy source economically to the conventional power grid system. It evaluates four different cases of penetrating wing turbine to the system. A 14 buses power system with one main 11 KV main feeder is chosen for the study. In the analysis procedure, wind turbine is connected to generation and distribution system with back to back converters as smart dc link as well as without back to back converters. According to the study result back to back converter improves system condition considerably; it reduces losses to a major extent and improves buses voltage profile.

The results of comparison of all cases reflect that best location for integrating wind turbine is in distribution system with a dc-link (in this study back to back converter). Benefits of connecting renewables sources with back to back converter exceed far more investment cost as it will payback for its cost in less than 2 years by reducing losses and improving voltage profile

The back-to-back converter connected in the system to reduce line current harmonics. It consists simply of a force-commutated rectifier and a force-commutated inverter connected with a common Dc –link. The properties of this combination are well known; the line-side converter may be operated to give sinusoidal line currents, for sinusoidal currents, the dc -link voltage must be higher than the peak main voltage, the dc -link voltage is regulated by controlling the power flow to the ac grid. The inverter operates on the boosted dc -link, making it possible to increase the output power of a connected machine over its rated power.

An important property of the back-to-back converter is the possibility of fast control of the power flow. By controlling the power flow to the grid, the dc-link voltage can be held constant. The presence of a fast control loop for the dc -link voltage makes it possible to reduce the size of the dc-link capacitor, without affecting inverter performance. In fact, the capacitor can be made small enough to be implemented with plastic film capacitors.

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