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Study the Integrated of Wind Farm with Utility Grid

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Abstract The wind farm must be installed at a site having suitable wind speed. This site may be far from the load. Then the wind farm must be connected to the load centers via transformer station to raise the voltage to the required values for transmission through long AC transmission line. There are some problems faces the interconnection between wind farm and load centers. Some of these problems are the way of wind turbine connection inside the farm, the collection point, the design of the transformer station and the design of overhead transmission lines. This paper introduces the most suitable methods for connecting the wind turbines to the collection point, the design of the transformer station and the AC overhead transmission lines according to the produced power from the wind farm. The most suitable methods have been applied on a wind farm installed at Gabl El-Zeat site which located on suze Gulf of Red sea, Egypt by using computer program based Matlab.

Keywords Wind farm, transformer station, AC overhead transmission lines, Matlab program

1. Introduction

There are several conceptual designs that are widely used in wind farm, such as Radial design, Ring design, Star design, and Direct design [1]. In the Radial design, the wind turbines are connected to a single series circuit. The reliability is established through loops between wind turbines. Considering the star design the wind turbines are distributed over several feeders, allowing the use of lower rated equipment. In direct design the wind turbines designed to be connected to a direct assembly system.

Since Modern wind turbines, WTs, typically generate power at low-voltage. Then this voltage must be raised to suitable higher voltage to minimize the transmission losses. In this paper the Repower wind turbine, WT type (6.2 M 126) has been used in the case study. This wind turbine has in its inside dry type transformer, T1, where its primary voltage 6.6 kV, and its secondary voltage is 33 kV [2].

The transmissions are considered with different voltage levels 33 kV, 66 kV, and 220 kV. Within this study, one transmission model is used consisting of two transformers and one transmission line, OHTL. At both terminals of the transmission lines a transformer was proposed with a half rated capacity of the wind farm. The selected transmission line is assumed to be a single circuit overhead line.

The overhead line can be designed as double circuits and having bundle conductor to transmit the full rated power of wind farm

2. Direct Design

The direct assembly system is the most appropriate way to connect the wind turbines so as to features derived:

- Each turbine unit is connected to a cable and a separate circuit breaker in the event of any errors in the turbine or cable are separated only turbine as in Fig. 1.
- Section area of medium voltage cables be similar which leads to easy control
- This method is compatible with The Egyptian Transmission System Code (ETSC) [3].

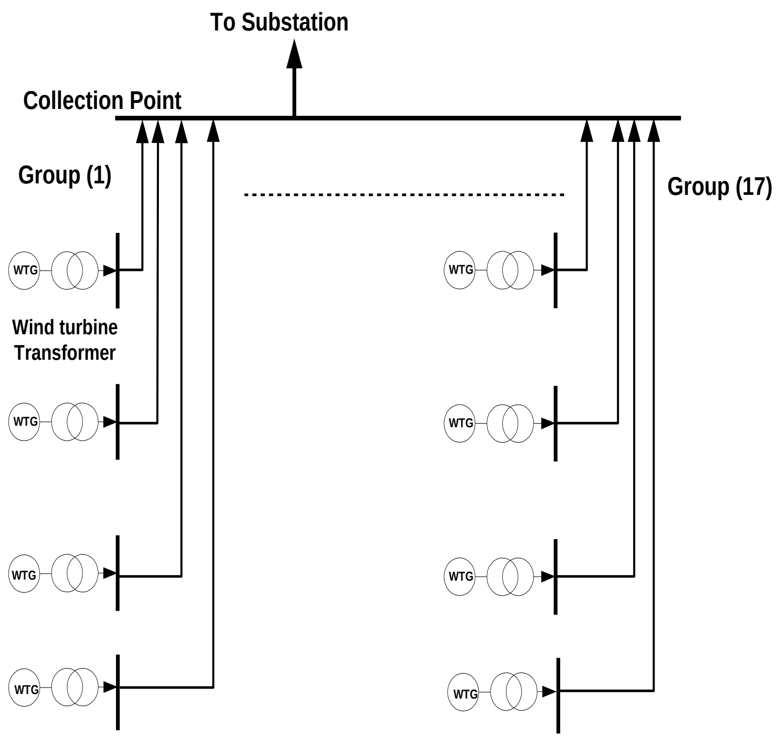

Figure 1: The Direct design for 68 wind turbines

3. Wind Turbine Module

The WT converts the wind energy to mechanical energy by means of a torque applied to a drive train. A model of the WT is necessary to evaluate the torque and power production for a given wind speed and the effect of wind speed variations on the produced torque. The power P_{wt} produced by the WT within the rotational speed interval [n_{min}; n_{max}] are proportional to the WTs blade radius *R*, air density ρ, wind speed u and a coefficient C_P [4, 6, 7].

$$P_{wt} = C_p\left(\frac{1}{2}\rho A_w u^3\right) = \frac{1}{2}\rho A_w u^3 C_p(\lambda, \beta) \qquad (1)$$

where,

C_p : The coefficient of performance.

ρ : The air density, is equal 1.225 kg/m^3 at sea level and at temperature T=298K

A_w : The swept area of the turbine, m^2.

u : The wind speed, m/s.

λ : Tip speed ratio

β : Blade pitch angle (degree)

Theoretically the Betz limit of C_p is 59.3% but in reality, the maximum C_p values in the range of 25-45% [4]. The coefficient of performance is not constant, but varies with the wind speed, the rotational speed of the turbine, and turbine blade parameters such as angle of attack and pitch angle. Generally, it is said that the power coefficient, C_p, is a function of, λ, and, β (deg): [4, 5, 6].

$$\lambda = \frac{\omega_R r_m}{u} \qquad (2)$$

Where;

r_m : The maximum radius of the rotating turbine, m.

ω_R : The mechanical angular velocity of the turbine , rad/s

The angular velocity ω_R is determined from the rotational speed n (r/min) by the equation.

$$\omega_R = \frac{2\pi n}{60} \tag{3}$$

Where,

n: The rotational speed, revolution per minute

Numerical approximations have been developed to calculate C_p for given values of β and λ. Here, the following approximation is used [4, 6]

$$C_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58*\beta - 0.002*\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \tag{4}$$

Where, λ_i is described by the equation:

$$\lambda_i = \frac{1}{\frac{1}{\lambda + 0.02*\beta} - \frac{0.03}{\beta^3 + 1}} \tag{5}$$

At rated wind speed, the rated electrical power output can be expressed as: [4]

$$P_{eR} = C_{PR}\eta_{mR}\eta_{gR}\frac{\rho}{2}A_w u_R^3 \tag{6}$$

Where, C_{pR} is the coefficient of performance at the rated wind speed u_R, η_{mR} is the transmission efficiency at rated power, η_{gR} is the generator efficiency at rated power, ρ is the air density, and A_w is the turbine area.

The efficiency for a gearbox or transmission efficiency is typically 90-95 percent and the efficiency for a generator is ranged from around 90 percent to almost 100 percent. The electrical power output of a wind turbine is a function of the wind speed, the turbine angular velocity, and the efficiencies of each component in the drive train. It is also a function of the type of turbine, the inertia of the system, and the gustiness of the wind. The *average power* $P_{e,ave}$ that would be expected from a given turbine at variation in wind speed, is evaluated by the following equation:

$$P_{e,ave}(t) = \begin{cases} 0, & u < u_c \\ C_P\eta_m\eta_g\frac{\rho}{2}A_w u^3 & u_c \le u < u_R \\ P_{eR}, & u_R \le u < u_F \\ 0, & u \ge u_F \end{cases} \tag{7}$$

Where,

P_{eR} : Rated Power of WTG, W

u_c : Cut-in wind speed m/s.

u_R : Rated wind speed m/s.

u_F : Cut-off wind speed m/s.

4. Overhead Transmission Line Design

The electrical performance of transmission line circuit is determined by its electrical resistance, inductance and capacitance. Such parameters depend on the physical properties of the conductors the distance between the conductor and the ground and the distance between the conductor and the other conductor along the line. When we considered in electrical system studies, these parameter are usually treated in form of the so called symmetrical components that are described as positive, negative and zero sequence impedances [8]. In deriving the equation for inductance and capacitance of transposed transmission lines balanced three phase current are assumed.

The positive sequence impedance can be estimated as: [8]

$$Z_{TL_1} = R_1 + jX_1 \tag{8}$$

Where:

R_1	Conductor resistance at the design temperature in (ohms/km)
X_1	Positive -sequence reactance (ohms/km)

The resistance of conductor at $20^o C$, one obtains the resistance at any temperature T, by;

$$R_{TDC} = R_1 = R_{20DC} *[1+\alpha(T-20)] \quad (9)$$

Where

α Temperature coefficient of resistance of ohms/degree

The positive sequence inductive reactance of a fully transposed equivalent three phase transmission line [8].

$$X_1 = \omega L_1 = \frac{\omega \mu_o a}{2\pi}\left[\ln \frac{D_m}{r_B} + \frac{1}{4n_2}\right] \quad (10)$$

Where:

ω	Angular frequency = $2\pi f$
L_1	Positive - sequance inductance in H/m
a	Conductor length in m,
Dm	Geometric mean distance,
μ_o	Constant of magnetic field = $4\pi * 10^{-7}$ H/m
r_B	Bundle conductor equivalent radius, m

Bundled Phase Conductors consist of a symmetric bundle of n_2 identical individual conductors. The equivalent radius is [8]:

$$r_B = r \sqrt[n_2]{\left(k_1 * \frac{S}{r}\right)^{n_2 - 1}} \quad (11)$$

Where:

n_2	Number of subconductor
r	Subconductor radius, m
r_o	Radius of bundle circle, m as shown in Fig. 2

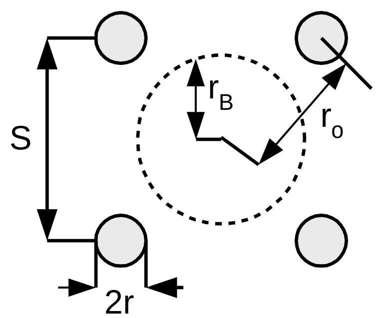

Figure 2: Equivalent Radius for Bundled Phase Conductors

$$k_1 = \frac{n_2^{(\frac{1}{n_2-1})}}{2\sin(\pi/n_2)} \quad (12)$$

$$r_o = \frac{S}{2\sin(\pi/n_2)} \quad (13)$$

Where:

S Subconductor distance within the bundle, will be used 400mm

From the above equation the geometric mean distance for single circuit line is,

$$D_m = \sqrt[n2]{(D_{AB}.D_{AC}.D_{BC})} \quad (14)$$

The total capacitance per phase is the so called positive sequence capacitance , C_1, while the capacitance to ground is the zero sequence capacitance, C_o .

For single circuit line with one or two earth wires, the earthed wires affect only the zero sequence capacitance while positive sequence capacitance can be taken as flowing [8]:

$$C'_{1S} = \frac{2\pi\varepsilon_o}{\left(\frac{D_M}{r_B}\right)} \quad (15)$$

Where:

ε_o Earth wire resistance per unit length in $\Omega\, km^{-1}$

r_B Bundle conductor equivalent radius

D_M Mean Geometric phase to phase distance, m

the positive sequence unit shunt admittance, Y_1' mho/km can be equated as:

$$Y_1' = G_1' + jB_1' \quad (16)$$

For OHTL the real terms G_1 are very small and can be neglected, meaning, $G_1 \cong 0$. This means that the following approximate relation can be equated [8].

$$Y_1' = jB_1' = j2\pi f C_1' \quad (17)$$

The ABCD constant for the transmission lines can be expressed in the series impedance (z) per unit length and shunt admittance (y) per phase [8].

These constant can be expressed as follows:

$$A = D = \cosh(\gamma l) \quad (18)$$

$$B = z_C \sinh(\gamma l) \quad (19)$$

$$C = \frac{1}{z_C}\sinh(\gamma l) \quad (20)$$

Where:

Z_C Surge impedance of the line.

γ The propagation constant

The propagation constant, is a complex expression given by

$$\gamma = \alpha + j\beta = \sqrt{zy} = \sqrt{(r + j\omega L)\times(g + j\omega C)} \quad (21)$$

The real part α is known as the attenuation constant, and the imaginary component β is known as the phase constant. β is measured in radian per unit length. the voltage and current at the Receiving end, are [8]

$$V_R = V_S * A - I_S * B$$
$$I_R = I_S * D - V_S * C \qquad (22)$$

Percent voltage regulation is defined as the percent change in receiving-end voltage from the no-load to the full-load condition at a specified power factor with sending-end voltage , V_S , held constant, that is, [9]

$$V.R = \frac{\left|\bar{V}_R\right|_{at\ No\ Load} - \left|\bar{V}_R\right|_{at\ Full\ Load}}{\left|\bar{V}_R\right|_{at\ Full\ Load}} * 100 \qquad (23)$$

Where:

$\left|\bar{V}_R\right|_{at\ No\ Load}$ Magnitude of receiving-end voltage at no-load

$\left|\bar{V}_R\right|_{at\ Full\ Load}$ Magnitude of receiving-end voltage at full-load with constant |Vs|,

V_S Magnitude of sending-end phase (line-to-neutral) voltage at no load.

To calculate the power loss, the first step is to determine the power factor at each end. In this study for the sending-end, the power factor is normally specified per design criteria. For the receiving-end, the power factor is found by determining the angle θ_R between the receiving -end current and voltage. The expression for receiving -end power factor is [9]

$$pf_R = \cos\left(\theta_{V_R(L-N)} - \theta_{I_R}\right) = \cos(\theta_R) \qquad (24)$$

Where:

pf_R Receiving -end power factor

$\theta_{V_R(L-N)}$ Angle of receiving-end line-to-neutral voltage

θ_{I_R} Angle of receiving-end current,

θ_R Angle difference between $\theta_{V_R(L-N)}$ and θ_{I_R}

Then, using the value of pf_R , the equation for calculating real power at the receiving -end is:

$$P_{R(3\Phi)} = \sqrt{3}\left|V_{R(L-L)}\right|\left|I_R\right|\cos(\theta_R) \qquad (25)$$

Where:

$P_{R(3\Phi)}$ Receiving -end real power in the line (MW).

But in this study the sending-end real power is the power produced by the wind farm. Using the calculated values from the above equations, real power loss in the line is found by

$$P_{L(3\Phi)} = P_{S(3\Phi)} - P_{R(3\Phi)} \qquad (26)$$

Where:

$P_{L(3\Phi)}$ Total real power loss in the line (MW).

Transmission line efficiency is: [8] and [9]

$$percent\ \eta_{tr} = \frac{P_{R(3\Phi)}}{P_{S(3\Phi)}} * 100 \qquad (27)$$

Where:

η_{tr}	Transmission line efficiency
$P_{R(3\Phi)}$	Total real power at the receiving-end
$P_{S(3\Phi)}$	Total real power at the sending-end

The phenomenon of violet glow, hissing noise and production of ozone gas is an overhead transmission line is called as corona Therefore some terms are important as critical disruptive voltage, discussed below. It is the Minimum phase to phase neutral voltage at which the corona occurs mathematically [11, 12]:

$$g_v = g_o * \delta * \left(1 + \frac{0.3}{\sqrt{r\delta}}\right) \quad kV/cm \qquad (28)$$

Where go = Breakdown strength of air is equal to 21.1 kV/cm (r.m.s) under normal weathering conditions (atmospheric pressure b = 76 cm Hg at t $25^{o}C$

$V_C = g_o * r * \log_e\left(\frac{d}{r}\right)$ =critical disrupt line voltage (29)

$\delta = \frac{3.92 * b}{(273 + t)}$ = air density factor (30)

Under standard condition, the value of δ is taken as unity (1)

$$V_C = g_o * \delta * r * \log_e\left(\frac{d}{r}\right) \qquad (31)$$

As per as surface condition if conductor, the expression is multiplied by the regulating factor mo. Finally, after consider overall, the critical disruptive voltage *i.e.* Vc

$$V_C = m_o * g_o * \delta * r * \log_e\left(\frac{d}{r}\right) \quad kV/phase \qquad (32)$$

Where:

m_o	Irregularity surface factor For polished conductor
=	0.98 to 0.92 for dirty conductor
=	0.87 to 0.8 for stranded conductor

Visual Critical Voltage, is defined as the minimum phase- natural voltage at which corona glow appears all the line conductors or mathematically [8, 9]

$$V_v = r\ m_o\ g_o \ln\left(\frac{d}{r}\right) = 21.1 m_o\ r\ \delta (1 + \frac{0.3}{\sqrt{r\delta}}) \ln\left(\frac{d}{r}\right) \quad kv \qquad (33)$$

The power loss to corona is given by [8] and [9]

$$P = 241 * (f + \frac{25}{\delta}) * \left(\sqrt{r/d}\right) * (V_P - V_C)^2 * 10^{-5} kw/km/phase \qquad (34)$$

Where:

f	Supply frequency in Hz
V_P	Phase to neutral voltage in rms.
V_C	Disruptive - voltage per phase in rms

Analysis of sag and tension of conductor is an important consideration in overhead transmission as well as distribution line design which can be estimated as [10]

$$d = \frac{w \times L^2}{8 \times T} \tag{35}$$

Where:

T	The tension of the conductor at any point P in the direction of the curve, Kg
w	The weight of the conductor per unit length, Kg/m
L	Horizontal distance, span , m

5. Results

A repower type of WTs with DFIG has been used. Table (1) shows characteristics of the selected the wind turbine generator, WTG. The hourly wind speed for the selected site represents the primary data required to design the controlled the wind turbine. The data has been obtained from the Egyptian Metrological Authority for Gabal Elzait site at Suez Gulf, Egypt.

Table 1: Characteristics of the selected WTG (Repower) [2]

P_R MW	6.15
u_C (m/s)	3.5
u_R (m/s)	14
u_F (m/s)	30
h (m)	95
D (m)	126
r_m (m)	63
A_w, m^2 $*10^3$	12.469
Operation interval rpm	7.7-12.1

In this paper the wind farm is designed to be divided into two circuits. MATLAB software is used to design wind turbine connected with collection point, design step up transformer and calculation the maximum power produced from wind turbine, the maximum power produced from wind farm, the ABCD constants for long transmission line, the receiving voltage and current, corona effect, sage tension , voltage regulation, and Power loses for OHTL.

a) **Collection Point for wind farm**

After producing the electric power of the wind turbines, they are transported by medium voltage underground cables. And to determine the area of the appropriate section that bear the quantity of current , the amount of energy transferred and total length are as follows:

- Set the area of the cable section

Since the maximum capacity produced from the wind turbine, WTG is 6.1492 MW as well as the power transformer located within the turbine and used in this study is 33 kV, and assume the Power factor is 0.98 . The current will be through the underground cable for one WTG, is

$$I_{one,WTG} = \frac{6.1492 * 10^6}{\sqrt{3} * 33 * 10^3 * 0.98} = 109.779 \cong 110 \quad Amp.$$

Then the underground cables will be used. These cables have aluminum conductor multi - core cables steel tap armored and isolated by XPLE. The cross section of the conductor is (3*50 mm^2).

- Set the length of underground cables:

In this study the limits of the wind farm are (6048 * 3591) meters and with a point of assembly distance of 500 meters from the wind farm as shown Fig. 3.

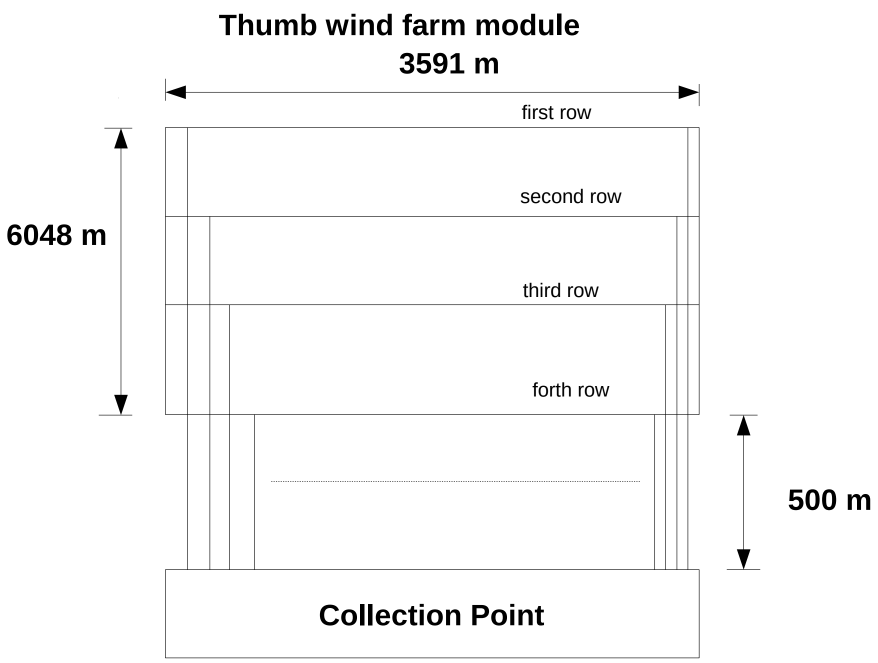

Figure 3: Placement of collection Point

The wind farm under study consists of :

- Number of turbine per row is =17
- Number of turbine per column is =4
- Total number of turbine is =68
- The area of wind farm is =(6048 m * 3591 m)

The length of underground cables for wind farm at first to forth row and first to seventeen column can be shown in Table (2).

Table 2: Length of 33 kV underground cables for wind farm

Length / Row	Length of cable for one WTG, m	Total length of cable for seventeen WTG, m
First Row	4091	69547
Second Row	2891	49198
Third Row	1697	28849
Forth Row	500	8500
Total Length of cable for wind farm ,m		156094

b) wind farm sub-station

Step up transformer sub-station can be divided into tow parts according to the voltage level:

- **part one for 66 kV voltage level**

In this part two step-up transformers, T_2, will be used for one circuit. The rated power for each transformer is 200 MVA, its primary voltage is 33 kV and its secondary voltage is 66 kV . The connection group Y-Y earthed . These transformers will operate at percentage load 55%, in parallel.

- **Part two for 220** kV **voltage level**

In this part two step-up transformer for one circuit, T_3, will be used for one circuit. The rated power for each transformer is 200 MVA, the primary voltage is 66 kV and secondary voltage is 220 kV. The connection group Y-Y earthed. These transformers will operate at percentage load 55%, in parallel.

Then the total number of transformers T_2 ,T_3 for wind power substation are equal four respectively. The transformers station is designed using two transformers for each voltage level, so that the plant is ready to carry out the whole load when any malfunction occurs in the transformer. The transformer impedance according to IEC60076 [12], will use the transformer have rated power 200 MVA, impedance 12.5% and ratio $\frac{X}{R}$ is equal 45.

c) Overhead Transmission Line

Since the conductivity of the conductor has an effect on the parameters of the OHTL as will as on the amount of energy transferred, has been used aluminum conductor steal reinforced, ACSR.

In this study the double circuit tower 220 kV, shown in Fig. 4 has been used. Table (3) shows the specification of this tower. In this study the class B has been used [12].

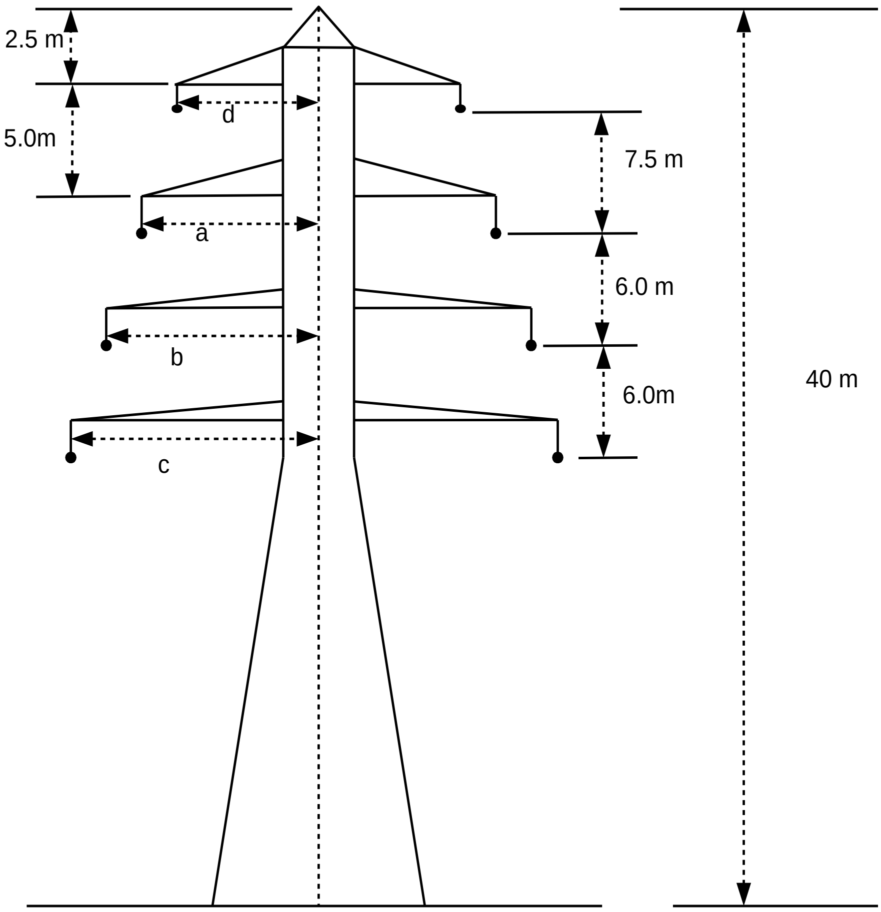

Figure 4: Double circuit tower, 220 kV

Table 3: The Tower specifications

	A	b	c	d
A	3.5	3.8	4.1	2.8
B	4.2	4.5	4.8	2.8
C	4.2	4.5	4.8	2.8

Table (4) shows the characteristics of Aluminum Conductor Steal Reinforced, ACSR, which chosen according to BS EN 50182- united kingdom [11].

And Table (5) shows the characteristics of Aluminum Conductor Steal Reinforced, ACSR will be chose as earthling wire according to BS EN 50182- united kingdom [11]. This OHTL will transmit the electric power from wind farm to the substation of Samalot sity. The long of OHTL form Gabal El zeat in suze to Smalot substation is about 285 km.

The positive sequence inductive reactance, x_1, and positive sequence admittance, Y_1, have been calculated taking into consideration the tower dimensions, double bundle conductor and the sub conductor distance within the bundle of 400mm. From the calculations it is found that the positive sequence impedance, Z_{TL1} and admittance per unit length , Y_1, as follows .

$$Z_{TL1} = 0.0378 + j0.2973 \quad \Omega / km$$

$$Y_1 = j3.7959*10^{-6} \quad moh/km$$

The generalized circuit constant A,B,C and D have been calculated in this study and their values have been found as follows:

$$A = 0.9545 \angle 0.342^o$$

$$B = 84.1004 \angle 82.8697^o$$

$$C = 0.0011 \angle 90.119^o$$

$$D = A$$

d) Wind farm Power Production:

According to the wind farm grid connection and the Egyptian transmission system code (ETSC) [3], the method of direct connection has been applied on the wind turbines. Figure 5 shows the hourly wind speed through the year hours. The wind farm under study has been designed to be divided into two circuits as shown in Fig. 6

The maximum power, minimum power and mean power which are produced from this wind are 417.9312 MW, 92.0812 MW and 256.13 MW respectively as shown in Fig. 7.

e) Receiving End Electrical Parameters

Knowing the electric parameters at the sending end, and by using design a Matlab program, the receiving-end electric parameters have been calculated. The receiving-end electric parameters are voltage, V_R, current, I_R , and power factor, pf_R.

Sending - end electric parameters which has been used are constant, V_S of $220 \angle 0^o \quad kV$, constant power factors of 0.95 lag. The hourly power produced from the wind farm under study represents the sending power which has been transmitted by the OHTL.

Table 4: OHTL characteristics (ACSR)

Designation	Nominal Cross Sectional area mm^2	Stranding and wire diameter mm				Max. DC Resistance at 20°C Ω/km	Rated strength		Approx. overall diameter mm	Approx. weight kg/m
		Aluminum		Steel			kN	kg		
ZEBRA	484.5	54	3.18	7	3.18	0.0674	45.9	4678.9	28.6	1.6208

Table 5: Earthed wire characteristics (ACSR)

Designation	Nominal Cross Sectional area mm^2	Stranding and wire diameter mm		Max. DC Resistance at 20°C Ω/km	Rated strength		Approx. overall diameter mm	Approx. weight kg/m
		Aluminum	Steel		kN	kg		
51-AL1/30-STIA	81.0	12	7	0.5644	42.98	4381.2	11.7	0.3747

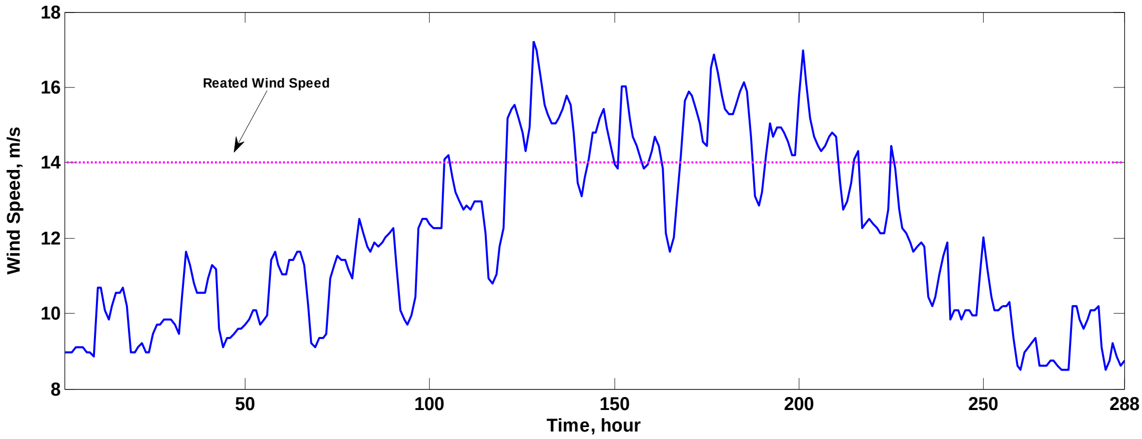

Figure 5: The hourly wind speed over the year

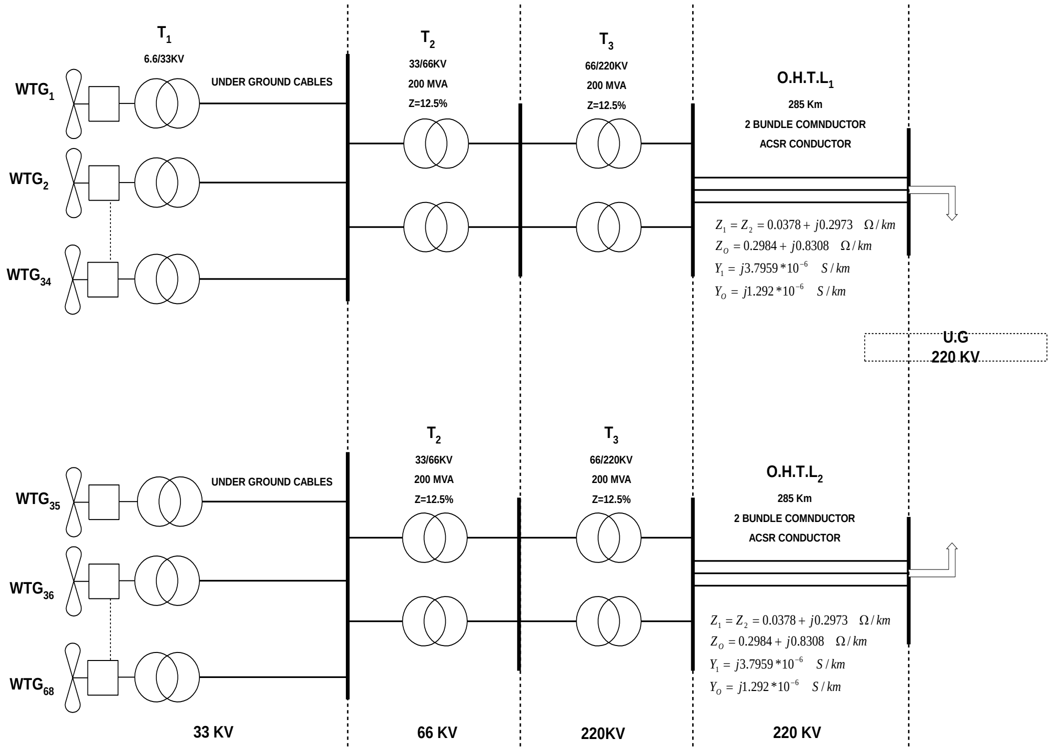

Figure 6: Wind Farm and Transmission system

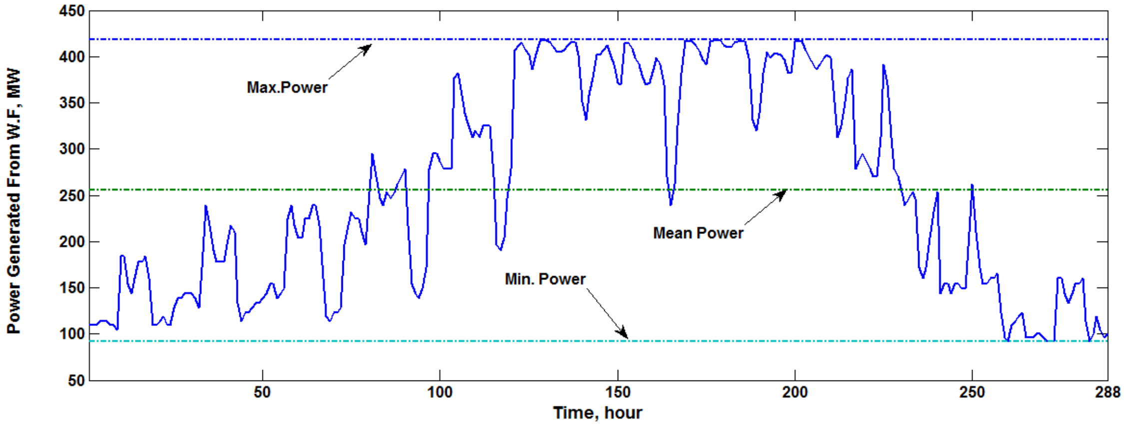

Figure 7: Hourly maximum, minimum and mean power production for wind farm

Figures (8) and (9) show the change in the voltage and current according to the change of the transmitted power through the year hours. Figure 10 show the relation between the power factor at receiving end and the transmitted power through the year hours.

Figure 11 displays the effect of transmitted power through the year hours on power losses, P_L. Also Fig. 12 reveals the effect the transmitted power through the year hours on transmission efficiency, η_{TL}.

Voltage regulation ratio, V.R, is defined as the percent change in receiving-end voltage from the no-load to the full-load condition. The influence of the transmitted power through the year hours on the voltage regulation ratio in shown in Fig. 13.

Critical Disruptive Voltage, Visual Critical Voltage and power loss due to the Corona have been calculated using equations from (28) to (34) and the following data to be found as 554.9198 kV, 616.7814 kV/km and 6.515 $*10^3$ kW/km/phase respectively.

The distance between conductors is 6.0075 m ,The radius of the conductor taking into account that the bundle conductor, $r = r_B = 0.0756m = 7.56cm$, Breakdown strength of air is $g_o = 21.1$kV/cm (r.m.s) under normal weathering conditions (atmospheric pressure b = 76 cm Hg at 25 ºC, irregularity surface factor, $m_o = 0.83$ for stranded conductor and the voltage phase to phase assuming equal to $v = \frac{220}{\sqrt{3}}\ kV$. The temperature has been assumed to be 38 ºC in this calculation.

The sage of the Zebra type connectors as well as the (51-AL1/30-STIA) earthed type connectors were calculated according to the data displayed in Tables (4) and (5).

Span has been taken to be 250 meter and equation (35). The values of Zebra type connectors and (51-AL1/30-STIA) earthed type connectors are 2.7063 m and 0.6682 m respectively.

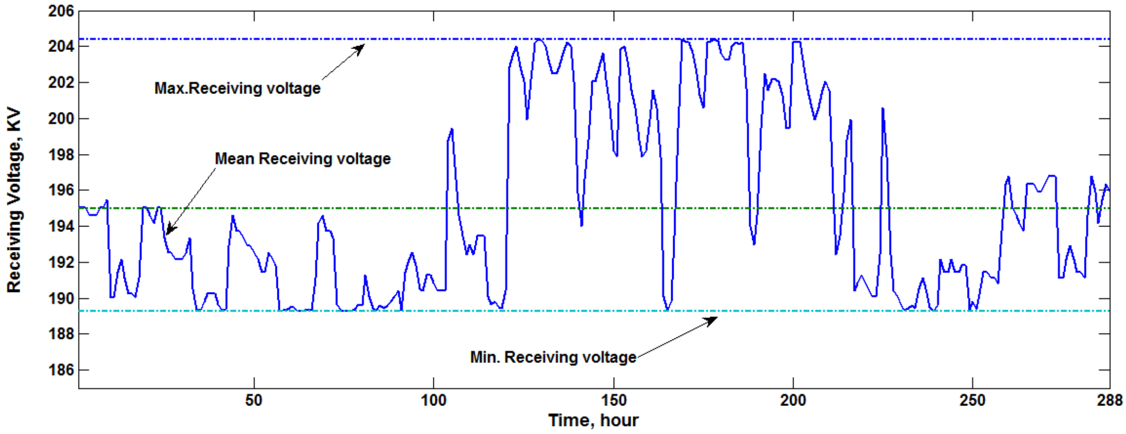

Figure 8: Receiving-end voltage, V_R

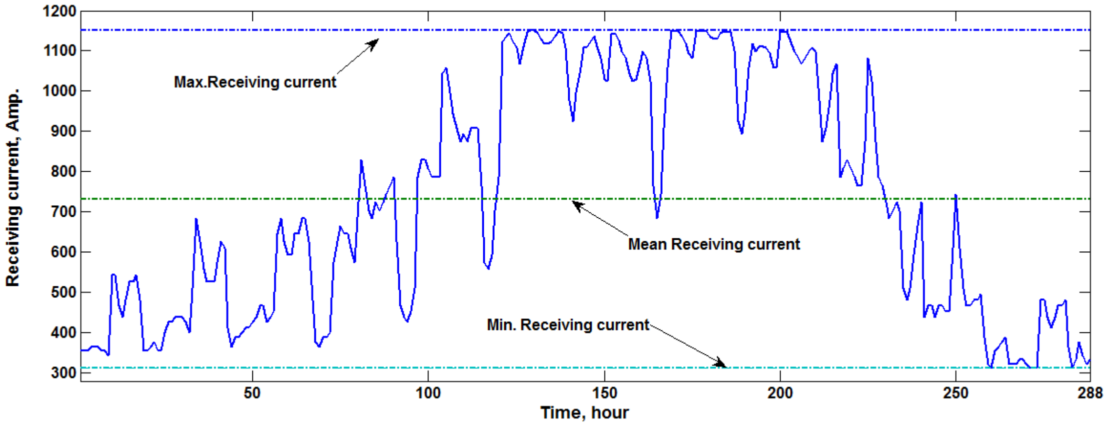

Figure 9: the current at receiving- end, I_R

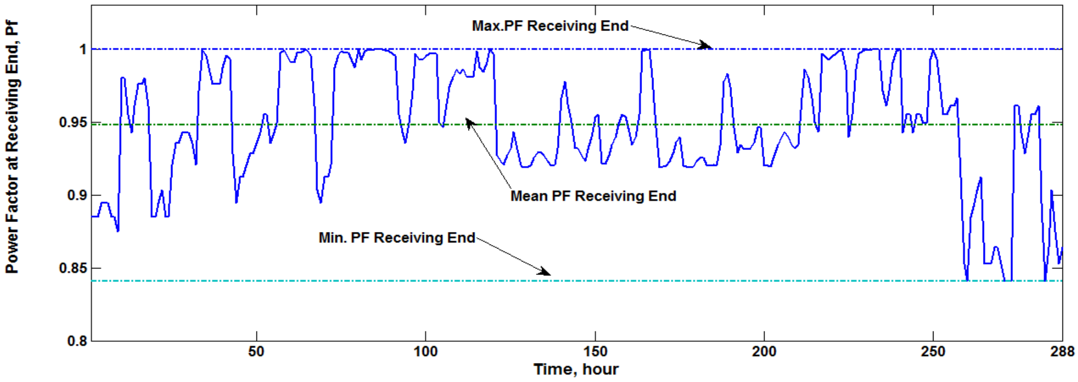

Figure 10: Receiving end power factor, pf

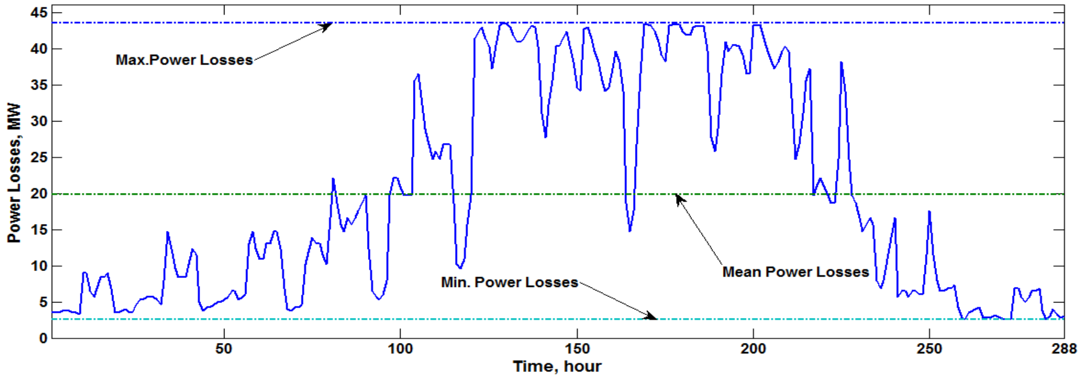

Figure 11: Power losses for transmission system, MW

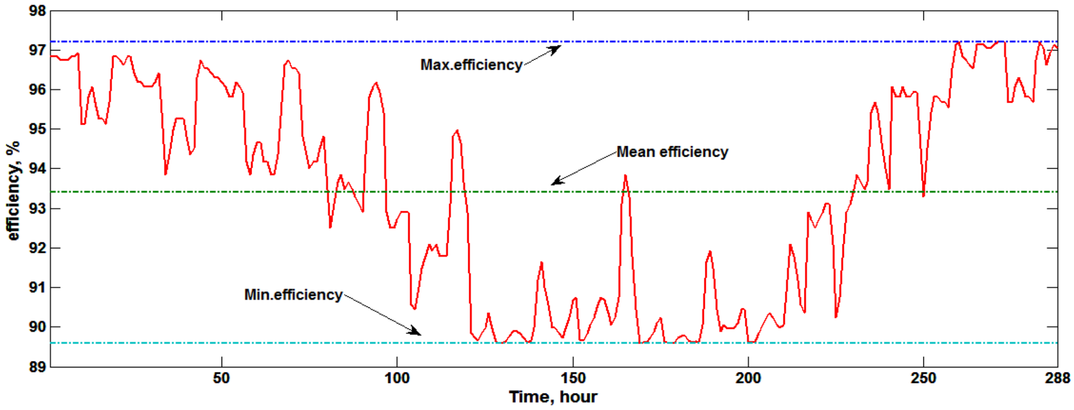

Figure 12: Efficiency for transmission system, MW

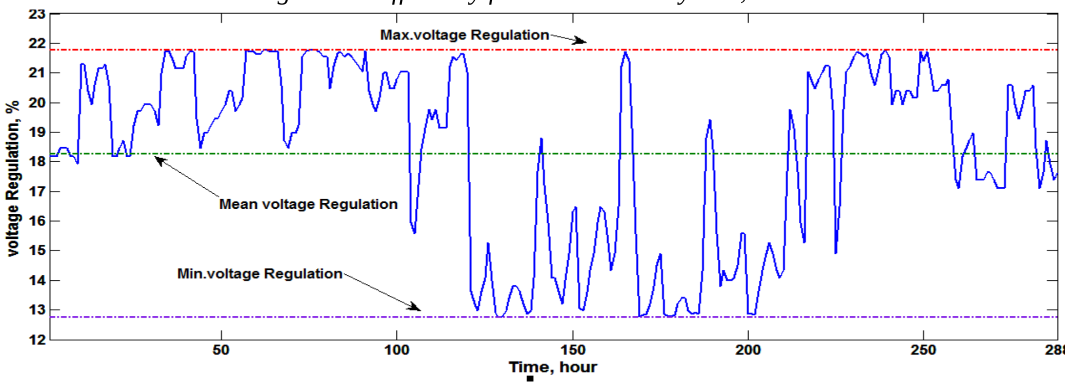

Figure 13: Percent of voltage regulation ratio, V.R, %

6. Conclusion

From this study it can be concluded that:

1. The use of the direct method in the systems linking the wind turbines and the collection point of the wind farm is most appropriate for the following reasons:
   - Each wind turbines unit is connected to a separate cable and circuit breaker, this leads to the occurrence of any error.
   - Use an equal section of the medium voltage cables in the connections within the collection point, which leads to easy control.
2. The use of Repower type of wind turbine, which contains the step up transformer, T_1 which rises the low voltage, 6.6 kV to medium voltage, 33 kV, is best suited to avoid voltage drop due to the length of low voltage cables, and rise the current generated at low voltage side.
3. The sub station transformer is designed to raise the voltage from 33 kV to 220 kV , by using two transformers ,T_2, T_3 at all voltage levels and at one circuit, have rated power 200 MVA for all transformer for the following reasons:
   - In the event of any malfunction or error in the first transformer, the second transformer is ready to carry the full load at any circuit. Also in the event of any malfunction in any circuit, the second circuit is ready to carry the full load. Each transformer will operate at percentage loads 55 %, which operate at parallel for one circuit.
4. There is no corona in the transmission line system and its sag is suitable.

References

[1]. G. Quinonez-Varela, G. Ault, O. Anaya-Lara, and J. McDonald, “Electrical collector system options for large off-shore wind farms,” Renewable Power Generation, IET, vol. 1, no. 2, pp. 107–114, 2007.
[2]. www.Repower.com
[3]. Egyptian Transmission Grid Code (ETGC) ," Wind Farm Grid Connection Code" March 2014
[4]. DR. GARY L. JOHNSON ,"WIND ENERGY SYSTEMS", hand book electronic edition, October 10, 2006
[5]. Brendan Fox, Leslie Bryans, Damian Flynn, Nick Jenkins, David Milborrow, Mark O’Malley, Richard Watson and Olimpo Anaya- Lara "Wind Power Integration Connection and System Operational Aspects"@ The Institution of Engineering and Technology Book Second Edition 2014
[6]. S.M. Muyeen, Junji Tamura, Toshiaki Murata, "Stability Augmentation of a Grid-connected Wind Farm" , Book, © 2009 Springer-Verlag London Limited.
[7]. Mustakerov, I. & Borissova, D. (2010)," Wind Turbines Type and Number Choice using Combinatorial Optimization", Renewable Energy, Vol. 35, No 9, pp. 1887-1894, Elsevier, ISSN: 0960-1481
[8]. Friedrich Kiessling, Peter Nefzger, Joao Felix Nolasco and Ulf Kaintzyk," Overhead Power lines: Planning, Design, Construction (Power Systems)" , book Publisher: Springer; 2003 edition
[9]. John J. Grainger, William D. Stevenson, "Power System Analysis", Book Copyright © 1994 by McGraw-Hill, Inc
[10]. Gonen, T. 2009, "Electrical power transmission system engineering analysis and Design", book 2nd ed. Florida: CRC Press
[11]. http://www.elsewedyelectric.com/Catalogs/PowerCables.pdf
[12]. "Network Protection and Automation Guide", NPAG, www.areva-td.com/protectionrelays