LOSSES MINIMIZATION IN ELECTRICAL POWER SYSTEM FOR ONE PART OF NATIONAL GRID OF JORDAN

Khalaf Alzyoud
Department of Electrical Engineering / Faculty of Engineering Technology
Al-Balqa Applied University. Jordan

ABSTRACT
In recent year, electric power demand has increased drastically due to superiority of electric energy to all other forms of energy and the expansion of power generation and transmission has been severely limited sequel to limited resources, environmental restrictions and lack of privatization. No matter how the power system is designed, losses are unavoidable and must be modeled before accurate representation.

Key words: Power Losses, Simulation, Transmission Line, Reduction, Power System, Electrical Power losses

http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=7&IType=6

1. INTRODUCTION
This paper discusses the types of the losses in the dc and ac generator (copper losses, magnetic losses, stray losses and hysteresis losses … etc) and the effect of these losses and how may reduce these losses to the minimum magnitude, for example the Copper losses is minimized in armature windings by using large diameter wire. In addition to the transfer stage studies which explain that the Electrical transmission system is the means of transmitting power from generating stations to different load centers and. Like other electrical system the transmission network also will have some power losses and voltage drop during transmitting power from sending end to receiving end, this project discuss the Major electrical transmission line losses (corona effect, proximity effect, …. Etc) and the best Solutions to Minimization these losses like when we increase the diameter of the wires the effect of corona in power system reduces considerably [1,2]. In the final stage, the delivery of electrical power is distribution system, there is a lot of reasons to the losses in this stage (Load Factor Effect on Losses, Lengthy Distribution lines….Etc) in this project we discu ss these reasons and the solutions that can help us to reduce these losses. Electric power systems are real-time energy delivery systems. Real time means that power is generated, transported, and supplied the moment you turn on the light switch. Electric power systems are not storage systems like water systems and gas systems. Instead, generators produce the energy as the demand calls for it. The system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage
electrical energy that is more suitable for efficient long-distance transportation. At the end we carry out a simulation project about the National Grid of Jordan (the buses between Amman north and Alsubahi) using ETAP program to minimizing the losses on the system. We edit this section by adding a static Var compensator in different places and then we note the effect of these alterations on losses and finally select the best Optimization placement that gives us less loss [3-6].

2. MATHEMATICAL CALCULATIONS

2.1. Mathematical Model for Power Losses

The main reason for losses in transmission and sub-transmission lines is the resistance of conductors against the flow of current. The production of heat in the conductor as a result of the flow of current increases its temperature. This rise in the conductor's temperature further increases the resistance of the conductor and this will consequently increase the losses [7]. This implies that Ohmic power loss is the main component of losses in transmission and sub-transmission lines. The value of the Ohmic power loss:

$L_{ohmic} = I^2 R \text{KW/km/phase}$

Where: $I$ current along the conductor and $R$ represents resistance of the conductor. The formation of corona on transmission line is associated with a loss of power, which will have some effect on the efficiency of the transmission line. The corona power loss for a fair weather condition:

$L_{corona} = 242 (f+25) \sqrt{\left(rd\right)} \cdot (V-V)^2 \cdot 10^{-5} \text{KW/Km/phase}$

Where:
- $f$ Represents the frequency of transmission,
- $\delta$ Denotes the air density factor,
- $r$ is radius of the conductor,
- $d$ represents the space between the transmission lines,
- $V$ is the operating voltage and
- $V.\cdot$ denotes the disruptive voltage.

Taking the total power loss on transmission lines to be the summation of ohmic and corona loss, we have:

$T_{loss} = L_{ohmic} + L_{corona}$ \text{i.e}

$T_{loss} = I^2 R + 242 (f+25) \sqrt{(rd)} \cdot (V-V)^2 \cdot 10^{-5} \text{KW/Km/phase}$.

The general form of this equation is given by:

$T_{loss} = I^2 \rho LA + 242 (f+25) \sqrt{(A\pi d^2)} \cdot (V-V)^2 \cdot 10^{-5} \text{KW/Km/phase}$.

Where
- $\rho$ -is the resistivity of the conductor,
- $L$- denotes the length of the conductor and
- $A$- is the cross-sectional area of the conductor.

2.2. Minimization of Power Losses

The problem of finding the optimum electric power loss during transmission can therefore be posed as minimize $(I,V,d)$

$T_{loss} = I^2 \rho LA + 242 (f+25) \sqrt{(A\pi d^2)} \cdot (V-V)^2 \cdot 10^{-5} \text{KW/Km/phase}$.

This is a nonlinear multivariable unconstrained optimization problem. Assuming that the transmission related factors are continuous, and then the last equation can be solved using the classical method of optimization.
To determine the stationary points of (6) we differentiate with respect to the selected variables to get:
\[\partial T\text{Loss} \partial I = 2\rho L A\]
\[\partial T\text{Loss} \partial V = 484 (f+25)/A\pi d 24. (V-V.) 10^{-5}\]
\[\partial T\text{Loss} \partial d = -121 (f+25)/A\pi 4. (V-V.) d - 3/210 - 5\]
These Equations give the extreme points as I = 0, V = V. And d \to \infty.

The second derivatives with respect to the variables are:
\[\partial^2 T\text{Loss} \partial I^2 = 2\rho L A\]
\[\partial^2 T\text{Loss} \partial I \partial V = 0\]
\[\partial^2 T\text{Loss} \partial I \partial d = 0\]
\[\partial^2 T\text{Loss} \partial V \partial I = 0\]
\[\partial^2 T\text{Loss} \partial V^2 = 484 (f+25)/A\pi d 24.10^{-5}\]
\[\partial^2 T\text{Loss} \partial V \partial d = -242 (f+25)/A\pi 4. (V-V.) d - 3/210 - 5\]
\[\partial^2 T\text{Loss} \partial d \partial I = 0\]
\[\partial^2 T\text{Loss} \partial d \partial V = -242 (f+25)/A\pi 4. (V-V.) d - 3/210 - 5\]
\[\partial^2 T\text{Loss} \partial d^2 = 3632. (f+25)/A\pi 4. (V-V.) d - 5/210 - 5\]

The Hessian matrix,
\[
H = \begin{bmatrix}
\frac{\partial^2 T\text{Loss}}{\partial I^2} & \frac{\partial^2 T\text{Loss}}{\partial I \partial V} & \frac{\partial^2 T\text{Loss}}{\partial I \partial d} \\
\frac{\partial^2 T\text{Loss}}{\partial V \partial I} & \frac{\partial^2 T\text{Loss}}{\partial V^2} & \frac{\partial^2 T\text{Loss}}{\partial V \partial d} \\
\frac{\partial^2 T\text{Loss}}{\partial d \partial I} & \frac{\partial^2 T\text{Loss}}{\partial d \partial V} & \frac{\partial^2 T\text{Loss}}{\partial d^2}
\end{bmatrix}
\]

\[
H = \begin{bmatrix}
\frac{2\rho L}{A} & 0 & 0 \\
0 & 484 (f+25) / \delta \sqrt{\frac{A}{\pi d^2}} & -242 (f+25) / \delta \sqrt{\frac{A}{\pi}} (V-V.) d^{-3/2} 10^{-5} \\
0 & -242 (f+25) / \delta \sqrt{\frac{A}{\pi}} (V-V.) d^{-3/2} 10^{-5} & \frac{3632}{2} (f+25) / \delta \sqrt{\frac{A}{\pi}} (V-V.)^2 d^{-5} 10^{-5}
\end{bmatrix}
\]

For which,
\[
H_1 = \begin{bmatrix}
\frac{2\rho L}{A} & 0 & 0 \\
0 & 484 (f+25) / \delta \sqrt{\frac{A}{\pi d^2}} & 0
\end{bmatrix} > 0
\]
\[
H_2 = \begin{bmatrix}
\frac{2\rho L}{A} & 0 & 0 \\
0 & 484 (f+25) / \delta \sqrt{\frac{A}{\pi d^2}} & 0
\end{bmatrix} = \frac{2\rho L}{A} . 484 (f+25) / \delta \sqrt{\frac{A}{\pi d^2}} . 10^{-5} > 0
\]
2.3. Discussion on Results

Since H1, H2 and H3 are all greater than zero, then it shows that the Hessian matrix of power losses over transmission lines is positive definite at the extreme values. Hence the power loss is minimum at I = 0, V = V, and d → ∞. Technically, this implies that the total power losses on transmission lines will only be minimum if [8-10]:

- Power is transmitted at a very low current along transmission lines. This will reduce the Ohmic or line loss on the conductors to the barest minimum. This conforms to the principle of electric power transmission.
- The operating voltage is equal to the critical disruptive voltage. When this happens, there is no ionization of air around the conductor and hence no corona is formed. Therefore, there will be no corona loss and.
- The spacing between the conductors on the transmission line should be large. This is because; an increase in the spacing between conductors reduces the electro-static stresses. This therefore reduces the corona effect. If the spacing between the conductors is made very large as compared to their diameter, there may not be any corona effect or losses on the line.

3. REACTIVE POWER COMPENSATION BASED ON FACTS DEVICES

The concept of Flexible AC transmission system has been proposed in 1995, which is called FACTs. The basic idea of FACTs is installing the power electronic devices at the high-voltage side of the power grid to make the whole system electronically controllable. The advances achieved in high power semiconductor devices and control technology makes the foundation of the development of FACTs. The FACTs devices are able to provide active and reactive power to the power grid rapidly. The power compensation achieved by FACTs devices could adjust the voltage of the whole system and the power flow could be satisfactorily controlled. Generally, the FACTs devices and technology could be divided into two generations [11, 12]:

- Dynamic devices and fixed capacitance devices. This is the first generation of the FACTs devices. In this period, the typical devices are including tap changing and phase changing transformer, synchronous generator and series capacitors. Except the series capacitors, which could also be called capacitor bank, others are dynamic devices. These devices are mainly controlled at the generation side of the power grid and the cost is typically expensive. When talk about the series capacitors, the drawback of this device could hardly be omitted. Since the device is made up of many fixed-capacitance capacitors, it could hardly be controlled to give the real not-fixed capacitance to the grid.
- Static state compensator. This is the second generation of the FACTs devices. It could be classified into two categories: thyristor-based devices and fully-controlled devices based compensator. The thyristor is called half-controlled device, because it can only be controlled to switch on but not to cut off. Static Var Compensator...

\[
H_3 = \begin{bmatrix}
\frac{2pL}{A} & 0 & 0 \\
0 & -484 \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi d^2}} 10^{-5} & -242 \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi}} (V - V_e) d^{-3/2} 10^{-5} \\
0 & -242 \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi}} (V - V_e) d^{-3/2} 10^{-5} & \frac{363}{2} \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi}} (V - V_e)^2 d^{-5/2} 10^{-5}
\end{bmatrix}
\]

\[
= \frac{2pL}{A} \left[\left(484 \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi d^2}} 10^{-5}\right) \left(\frac{363}{2} \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi}} (V - V_e)^2 d^{-5/2} 10^{-5}\right) - \left(242 \left(\frac{(f+25)}{\delta}\right) 4 \frac{A}{\sqrt{\pi}} (V - V_e) d^{-3/2} 10^{-5}\right)^2 \right] > 0
\]
(SVC) and Thyristor-Controlled Series Capacitor (TCSC) are included in this category. The fully controlled devices mainly involve GTO etc. The Static Compensator (STATCOM), Solid State Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and HVDC-Voltage Source Converter (HVDC-VSC) are included in this group [13].

3.1. The Thyristor-controlled Reactor (TCR)

The configuration of a typical TCR is shown below. The controller is an anti parallel thyristor pair. Each of them conducts on alternate half cycles of the supply frequency. The other important sub-device of TCR is the inductance L. The TCR mainly acts as a controllable susceptance. TCR is also the fundamental component of the SVC and TCSC. When talked about TCR, people always use this device as a shunt compensator [14-17].

![Figure 3.1 The Thyristor-controlled Reactor (TCR).](image)

3.2. The Static VAR Compensator (SVC)

SVC is the most popular FACTs devices in the recent years. It typically consists of a TCR in parallel with a capacitor bank. From the operational viewpoint, the SVC acts as a shunt connected variable reactance. Compared to the TCR that can only generate reactive power, SVC cannot only generate but also absorb reactive power. SVC is also a shunt connected device, and is always modeled into three phase form[18-21].

![Figure 3.2 The Static VAR Compensator (SVC)](image)
3.3. The Thyristor-controlled Series Compensator (TCSC)

A TCSC is made up of a TCR in parallel with a fixed capacitor. Compared to TCR and SVC, TCSC is a series connected controller instead of ashunt-connected device. Therefore, TCSC is always represented in single-phase form instead of three-phase form, and is always comprised of one or more sub-modules. The basic structure of a TCSC is shown below. TCSC changes the electrical length of the existing transmission line with negligible delay. This characteristic makes TSCS be used to perform the fast active power flow regulation. But adding TCSC into the existing system will change the phase angle of the buses. This trait is not the same as that of the SVC.

![Figure 3.3 The Thyristor-controlled Series Compensator (TCSC)](image)

3.4. The Static Compensator (STATCOM)

A STATCOM is mainly consists of a voltage source controller and the corresponding shunt-connected transformer. Although it acts like a static part of the rotating synchronous device, its absence of moving parts makes it owns faster speed than the older dynamic compensators. The STATCOM performs the same voltage regulation function as the SVC introduced before and it is also a shunt connected device.

![Figure 3.4 The static compensator (STATCOM)](image)

3.5. The Solid State Series Compensator (SSSC)

The SSSC acts like a phase shifter and the structure of it is similar to a STATCOM but the voltage source controller is serially connected to a transformer instead of shunt-connected as in a STATCOM. The basic topology of a SSSC is shown below.
3.6. The Unified Power Flow Controller (UPFC)

It is made up of two voltage source controllers sharing the same capacitor at their dc voltage controlled side. One voltage source controller is in parallel with one side of a transmission line and the other voltage source controller in the UPFC is in series connect to the other side of the same transmission line. The basic structure of the UPFC is shown in the Figure 3.7. The UPFC can simultaneously control the active and reactive power flow and voltage magnitude. However it has little effect on voltage angle.

4. RESULTS

Case one: without adding SVC. Bus system in first running

|-----------|-------------|-----------------|-------------------|-----------|-------------|
Case two: after adding SVC at bus A6. Bus system after adding svc at bus A6

Table 2 Branch losses summary report

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30.403</td>
<td>-399.468</td>
<td>30.403</td>
<td>-399.468</td>
<td>20.204</td>
<td>-348.929</td>
</tr>
</tbody>
</table>

Case three: after adding SVC at bus A7. Bus system after adding SVC at bus A7

Table 3 Branch losses summary report

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>29.914</td>
<td>-392.683</td>
<td>29.914</td>
<td>-392.683</td>
<td>20.142</td>
<td>-349.037</td>
</tr>
</tbody>
</table>

5. DISCUSSION

At first, I would like to mention that in the ETAP program the buses were shown in different colors varies depending on the voltage loading on the bus, for example, if the bus loading is critical, and then the bus color will be red. And if the bus loading is marginal, then the bus color will be pink. Plus if the bus is normal its color must be black. Now we will review the most effecting system data before adding any modification, and after adding the SVC in the two places, which were as follows:

The percentage voltage drop. Without modifications

- The percentage voltage drop on T22 = 2.56%.
- The percentage voltage drop on Line2 = 5.18%.

The percentage voltage drop after adding SVC at bus A6

- The percentage voltage drop on T22 = 4.79%.
- The percentage voltage drop on Line2 = 1.89%.

The percentage voltage drop after adding SVC at bus A7

- The percentage voltage drop on T22 = 4.69%.
- The percentage voltage drop on Line2 = 0.20%

We can see that adding the SVC in the bus A7 is best than it in the bus A6. That because the percentage voltage drop reduction in the second case in Line2 is bigger than it in the first case, neglecting the small rising in the percentage voltage drop in T22.

The Branch losses and total losses

The branch losses without modifications

- The P losses in T17 = 5.4kw, and the Q losses in T17 =100.9kvar.
- The P losses in T22 = 5.3kw, and the Q losses in T22 = 98kvar.
- The P losses in T24 = 2.5kw, and the Q losses in T24 = 58.7kvar.
- The P losses in Line2 = 209.1kw, and the Q losses in Line2 = -9462kvar.
The total $p$ losses = 20.211Mw, and the total $Q$ losses = -350.327Mvar.

**The branch losses after adding SVC at bus A6**
- The $P$ losses in $T17$=5.1kw, and the $Q$ losses in $T17$ =94.5kvar.
- The $P$ losses in $T22$=54.8kw, and the $Q$ losses in $T22$=1019kvar.
- The $P$ losses in $T24$=19.5kw, and the $Q$ losses in $T24$ = 462.3kvar.
- The $P$ losses in Line2=132.7kw, and the $Q$ losses in Line2= -9427.7kvar.
- The total $p$ losses = 20.204Mw, and the total $Q$ losses = -348.929Mvar.

We can see that adding the SVC in the bus A7 is best than it in the bus A6, that because the losses in Line2, and $T17$ had been reduced, and total losses reduction in the second case is bigger than it in the first case, neglecting the losses rising in the branches $T24$, and $T22$.

**The power factor**

*The branch percentage power factor without modifications*
- The percentage power factor in $A6$=52.7%
- The percentage power factor in $A7$=21.2%
- The percentage power factor in $A8$=21.2%
- The percentage power factor in bus32=42.5%

*The branch power factor after adding SVC at bus A6*
- The percentage power factor in $A6$=93.7%
- The percentage power factor in $A7$=93.7%
- The percentage power factor in $A8$=93.7%
- The percentage power factor in bus32=93.7%

*The branch power factor after adding SVC at bus A7*
- The percentage power factor in $A6$=95.7%
- The percentage power factor in $A7$=95.7%
- The percentage power factor in $A8$=95.7%
- The percentage power factor in bus32=95.7%

We can see that adding the SVC in the bus A7 is best than it in the bus A6, that because the percentage power factor is higher when we add SVC in bus A7.
6. CONCLUSION

Taking all what we have presented in consideration the most satisfactory conclusion that it is a priority to establish a bases for a robust understanding and highlight the necessity for deep knowledge about reduction of losses in the whole power system, so when we know the main reasons that makes losses on the main parts of electrical system we can make studies to minimize these losses, also its very important to determine the cost that result from the loses. One should note here that using large diameter wire its useful to minimize the copper losses in DC generator, also heat-treated silicon steel laminations are used in most DC & AC generator armatures. Careful maintenance can be instrumental in keeping bearing friction to a minimum. Also there's a steps that taken in consideration in DC & AC generator is clean bearings and proper lubrication are essential to the reduction of bearing friction. Other consideration that taken as power factor correction and is achieved by switching in or out banks of inductors or capacitors.

In transmission line there can be a resonance occurring at a certain capacitive value. This will lead to very low impedance and may cause very high currents to flow through the lines. We takes FACTs in our project, its function is to provide active and reactive power to the power grid rapidly. In distribution line, using comfortable length & size of conductor is useful for reducing the losses; also Distribution Transformers must locate near the load centers. Performing regular inspection to randomly select and any suspected customers, conducting regular campaign to increase the awareness of the customers with the efficient use of electricity.

REFERENCES


