

# Design and Analysis of hypothetical Electrical Network for Power factor Improvement Calculations

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## ABSTRACT

This project represents any distributed area having residential, Commercial and industrial loads. The main reason for this project is the difficulty for getting the data because there is no specific department for the technical specification. Also, the equipment installed in the network came from several companies. It took more than two months to get complete data and a sample of network, but no clear data was obtained, so I invented a network like real one.

I used ERACS software, which is provided by the department of electrical and computer engineering and choose many elements form its library. It was useful and had a good manual.

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## I. INTRODUCTION

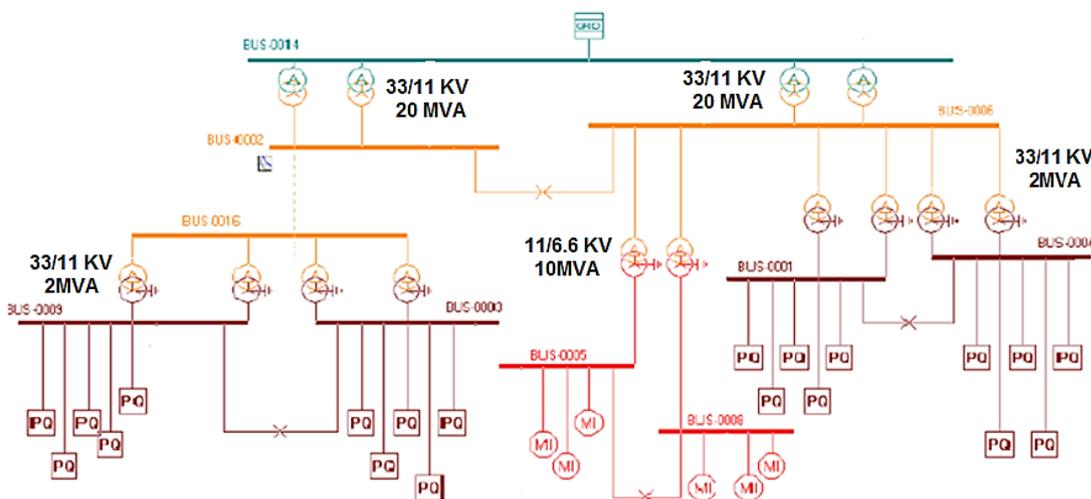
The ERACS' software has many advantages including the following:

- Easy to use by professional engineers who work in industrial field by entering the data and editing it with simple way.
- Useful database that can be used by different types of experts in researchers and marine.
- It can get to the help support in case of facing problem during using the application.
- Continual improvement to applications that help to develop its efficiency.

- There is available staff for fixing any problems that might users face them during work.
- The software can be used for different types of networks such as radial or mesh systems.
- The application can be used easily after entering the data for one time only.

### 1.1 Project network

By using ERACS, I represent residential and industrial loads which can be a mix of factories and offices and homes. The network has 5 levels of voltages which are 33KV, 132KV, 11KV, 6.6KV and 415V. Also, there are bus bars.



The aim of the project is to improve the power factor for the whole network by adding shunt capacitor banks which need the knowledge of the required reactive power. The figure below shows the project network:

### 1.2 Sources of Reactive Power

There are many resources for reactive power generation; some of them can regulate voltage and can be described as follows:

#### 1- Synchronous alternator:

Synchronous machines can be made to generate or consume the reactive power by controlling the excitation. The output of a synchronous machine when used as a generator will feed the loads by

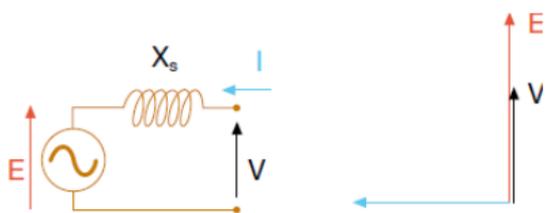


Figure 1: Under excited synchronous machine

transmitting power in overhead lines or cables in a network. It is possible to adjust generators automatically to keep the voltage out constant.

#### 2- Synchronous Compensators:

These are organised in the network by connecting synchronous machines without a connected load. The main function for these machines is to compensate the excessive reactive power or to supply reactive power in case of over excited operation. They can regulate the voltage and control the flow of reactive power in any different voltage level, on the other hand the main drawback for synchronous compensators are the high cost of maintenance and insulation at the distribution level.

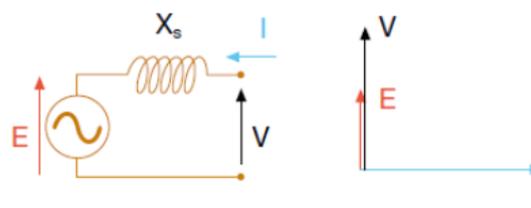


Figure 2: Overexcited synchronous machine

#### Where

- E is the voltage across the phases of the stator
- V is the phase voltage feeding the alternator terminals by the network
- I is the stator current
- $X_s$  is the value of stator reactance

#### 3- Static Var Compensator

It can control the reactive power by adjusting voltage through using high-speed thyristor switching/controlled devices and consists of a coupling transformer, thyristor valves, reactors, and capacitance (often tuned for harmonic filtering). The main merit of using SVCs is the simplicity of mechanical switches compensation schemes and their near-instantaneous response to change in the system voltage by operating at the zero point to reach higher reactive power values. There are many advantages to Static var compensators, which include:

- Affordable price.
- Better stability for the system in case of normal or transient cases.
- Minimizes the voltage drop to the load reign.
- Reduction for transmission losses.
- Loads for lines can be controlled in better ways.
- SVCs are more dependable when compared to dynamic compensation methods.
- Drives the load in parallel circuits equally.

It can explain the way for static var compensator working idea by two main ways to control reactive power. the first is by using thyristor-switched shunt capacitors which uses a divided capacitor bank to provide control with a half cycle delay. The other method is by using thyristor-switched shunt reactors which work by delaying the closing thyristor for the current crossing the reactor.

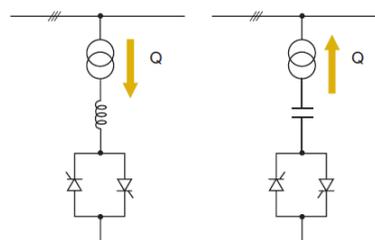


Figure 3: The picture on the left show TCR type whereas the picture on right show TSC type for Static Var compensator

#### 4- Capacitive Compensators

The capacitor has an electric element which functions by storing electrical energy for future use. Capacitors are popular electric elements and are used widely in electronic circuits as filters after rectifying the alternating current.

They consist of two surfaces made of conductor with insulation material between them.

It is possible to calculate the capacitance for any capacitor using two methods; the first method involves using the formula  $C = \frac{Q}{V}$ .

Where,

- C is the capacitance in  $\mu$  Farad
- Q is electric charge in coulomb
- V is the voltage produced between the capacitor plates

In the past, the capacitor bank system used to be isolated by an impregnated material for protection against humidity and gases which could produce an electrical discharge (PD). However, nowadays new designs utilise dry mechanisms which are environmental safer. The capacitor can take different shapes such as cylinder, sphere, or plane

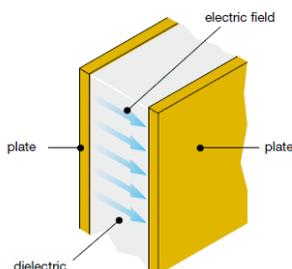


Figure 4: The construction of capacitor

#### 5- Overhead Lines and Underground Cables

In any electric network the carrier for the current is either cables or overhead lines. These carriers can be a source of reactive power with the consumer depending on the voltage level. For example, during normal working voltage both cables and overhead lines generate huge amounts of electro magnetic fields resulting in reactive power. Cables with high voltage levels such as those in transmission can also produce reactive power because the amount of the power produced by the electromagnetic field is higher than that taken from the network to the cables. There is also additional equipment which serves as a source of reactive power such as power transformers. The transformer can be classified as a reactive load because of its winding which represents positive reactive power (consumer).

#### 6- The electrical loads

Electrical loads are classified in three categories and include resistive, inductive and capacitive types. Motors such as induction or synchronous can emit an electromagnetic field from its coil and is considered a consumer, whereas fluorescent lights produce reactive power. Another consideration for cables and overhead lines is that they can be a generator or consumer for reactive power depending of the power flow in the network.

#### 1.3 Loads

The load can be divided into two types. The first table show residual and office loads available with location for each on the network

Table 1: The residential load for each bus bars

Substation	Load Name	location	Active power MW	Reactive power MVAR	Power factor
S/S2	load1	BUS-0003	0.280	0.400	0.7
S/S2	load2	BUS-0003	0.320	0.400	0.8
S/S2	load3	BUS-0003	0.280	0.400	0.7
S/S2	load3	BUS-0003	0.280	0.400	0.7
S/S2	load5	BUS-0003	0.328	0.400	0.82
S/S1	load1	BUS-0009	0.280	0.400	0.7
S/S1	load2	BUS-0009	0.320	0.400	0.8
S/S1	load3	BUS-0009	0.280	0.400	0.7
S/S1	load3	BUS-0009	0.280	0.400	0.7
S/S1	load5	BUS-0009	0.328	0.400	0.82
S/S6	load1	BUS-0004	0.280	0.400	0.7

S/S6	load7	BUS-0004	0.200	0.250	0.8
S/S6	load4	BUS-0004	0.300	0.400	0.75
S/S6	load5	BUS-0004	0.328	0.400	0.82
S/S6	load8	BUS-0004	0.287	0.350	0.8
S/S5	load2	BUS-0001	0.320	0.400	0.8
S/S5	load3	BUS-0001	0.280	0.400	0.7
S/S5	load6	BUS-0001	0.240	0.300	0.8
S/S5	load7	BUS-0001	0.200	0.250	0.8
S/S5	load8	BUS-0001	0.287	0.350	0.8

The second type is industrial loads which have induction motors with high power consumed and low power factor. This can be seen in the table below:

Table 2: The industrial load for each bus bars

Substation	Motor Name	location	Active power MW	Reactive power MVAR	Power factor	RATED Voltage KV
SS3	Motor 1	BUS-0005	1.18	1.5	0.78	6.6
SS3	Motor 2	BUS-0005	1.55	2	0.775	6.6
SS3	Motor 1	BUS-0005	1.18	1.5	0.78	6.6
SS4	Motor1	BUS-0008	1.18	1.5	0.78	6.6
SS4	Motor2	BUS-0008	1.55	2	0.775	6.6
SS4	Motor1	BUS-0008	1.18	1.5	0.78	6.6

#### 1.4 Transformers

To get the suitable transformers to each substation, we need to calculate the consumed power to each load from the two tables presented above.

For example, the consumed power for bus 9 can be shown as follows:

Total MVA = MVA load 1 + MVA load 2 + MVA load 3 + MVA load 4

$$= \frac{0.28}{0.7} + \frac{0.32}{0.8} + \frac{0.28}{0.7} + \frac{0.28}{0.7} + \frac{0.328}{0.82} = 2 \text{ MVA}$$

Then, applying the same method to get the total power needed to each substation, we will get the suitable transformers to each substation as follows:

Table 3: The total loads required to each substation

Substation	Total load Power	Transformer Power
S/S1	2 MVA	2 MVA
S/S2	2 MVA	2 MVA
S/S3	4.94 MVA	10 MVA
S/S4	5.02 MVA	10 MVA
S/S5	1.708 MVA	2 MVA
S/S6	1.808 MVA	2 MVA
S/SA	20 MVA	20 MVA
S/SB	20 MVA	20 MVA

The connection of the transformers was delta/ star or delta/earthed star. The first connection has the benefit of preventing moving any zero current, whereas the second one keeps the zero-current moving inside the delta winding only.

Also, the design of this network ensures the firm capacity for transformers which mean that in case of fault or maintenance to any transformer for same bus bar the second one can handle the load without any problems. The network has single bus bars with sectionalizer, which is located between

two sections of any bus bar to open and close the circuit in case of maintenance for the bus that needs more power to the loads.

There are special transformers with rating 11/6.6 KV for feeding the industrial loads which is a huge induction machine that has a low power factor. All the details of transformers used in the network are shown in the table below:

Table 4: The technical specification to each transformer

High side HV	Low side LV	Rating MVA	Resistance %	Reactance %	connection	number
33 KV	11KV	20	0.5	12	Dy 11	4
11KV	0.415 KV	2	0.4	5.8	Dyn 11	8
11KV	6.6 KV	10	0.002	0.04	Dyn 11	2

### 1.5 Fault level

It is required to make a study for the fault rating to each bus bar in the designing period to identify the short circuit rating to the switchgear

The following table includes the details for all bus bars in the network which includes voltage, frequency, and both of three- and single-phase fault levels.

Table 5: The fault level for each bus bar

Bus bar name	Nominal Voltage Kv	Nominal Frequency Hz	3 <sub>PH</sub> regulation Fault level MVA	3 <sub>PH</sub> Fault level MVA
BUS-0001	0.415	50	250	73.586
BUS-0002	11	50	250	125.809
BUS-0003	0.415	50	250	59.246
BUS-0004	0.415	50	250	73.586
BUS-0005	6.6	50	250	142.634
BUS-0006	11	50	250	164.629
BUS-0008	6.6	50	250	142.634
BUS-0009	0.415	50	250	59.246
BUS-0014	33	50	1000	528.375
BUS-0016	11	50	250	101.697

Using Eracs software, I applied 3 phase faults on bus bar 16 and got current equal to 5.338KA. Then the fault level can be obtained by the following formula:

$$\text{Fault level in MVA} = \sqrt{3} \times V_{\text{Line}} \times I_{\text{Line}} = \frac{\sqrt{3} \times 11 \times 10^3 \times 5.338 \times 10^3}{10^6} = 101.702 \text{MVA}$$

Table 6: The standard fault level in the UK

Voltage level.	Design Fault Level.
6.6kV	250MVA $I_{sc3\phi} = 21.87\text{kA}$ , $I_{sc\phi\text{-earth}} \leq 3.0\text{kA}$
11kV	250MVA $I_{sc3\phi} = 13.12\text{kA}$ , $I_{sc\phi\text{-earth}} \leq 3.0\text{kA}$
33kV	1000MVA $I_{sc3\phi} = 17.5\text{kA}$ , $I_{sc\phi\text{-earth}} \leq 3.0\text{kA}$
132kV	5000MVA ( $\cong 21.87\text{kA}$ three-phase or phase-earth, whichever is higher.)
275kV	15000MVA ( $\cong 31.49\text{kA}$ three-phase or phase-earth, whichever is higher.)

The following table shows the cable specification

Table 7: The cable speciation

cable speciation	The core
Conductor material	Copper
Rated current in Ampere	299 A
Fault current capacity for 1 second	13.6 KA
Cross sectional area in mm <sup>2</sup>	95 mm <sup>2</sup>
AC resistance at 50Hz and 90°C	0.247
Reactance at 50Hz and 90°C	0.106
Zero sequence resistance at 20°C	0.706
Zero sequence reactance at 20°C	0.0580

### 1.6 Power factor correction methods

Power factor correction can be done by capacitor banks using several methods related to different aspects in the network. These factors could include the cost of electric bills, amount of saving in case of using the capacitors, losses in transmission lines, area on the capacitors, cost of maintaining capacitors, and the temperature in the area of the capacitors.

### 1.7 Capacitor's insulation

The main methods for using capacitor banks related to location include:

#### 1- Global compensation

This method can be implemented by attaching the capacitor bank to the main low-tension board and making the capacitor on duty when the load is available. The benefits of using this method include:

- By minimizing the consumed amount of reactive power, this leads to a reduction in the cost of reactive power which positively impacts total tariff penalties.
- Helps reduce the apparent power usage of the load.
- Give excessive capacity to the power transformers which can be used to feed additional loads in the future and extend the lifetime of the transformer.
- The network life can be extended because of the power controlled in the main bus bar.

The magnetizing current still moves through the cables which have the same cross section area and copper loss.

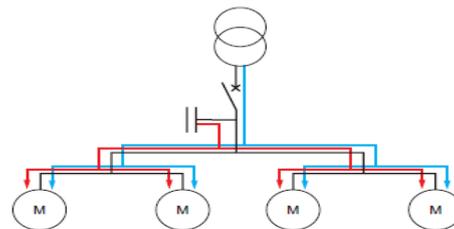


Figure 6: The global compensation technique

#### 2- Sector compensation

This method can be applied by connecting the capacitor banks to each individual bus bar, which leads to adjusting the reactive power to each bus bar. By making use of sector compensation, it is possible to realise the following:

- Using less reactive power can help reduce customer cost.
  - The quality of used apparent power becomes less compared to network prior to compensation.
  - Better investment for existing transformers through load reduction.
  - Minimizing the current crossing in the cables which help to add extra loads in the future or reduce the area of cables.
  - Reduction for the copper loss in the same used cables.
  - This method has economic advantages.
- There are several further comments on this method, and these can be summarized as follows:
- The magnetizing current moving through the cables connecting the main board to each sector is not a cause for cross sectional area and the copper loss improvement in the cables.
  - It is possible acquire excessive load voltage values when changing the load which can be damaging to the loads.

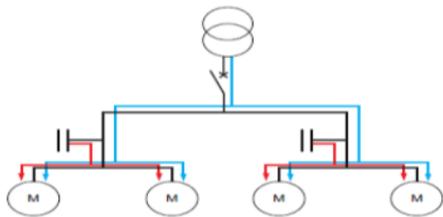


Figure 7: The way for using sector compensation

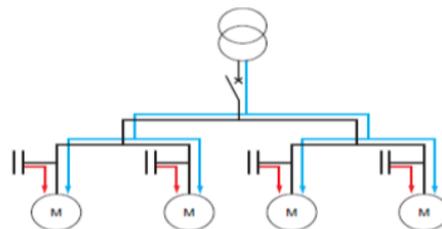


Figure 8: The use of individual compensation

### 3- Individual compensation

This installation method can be made by connecting each specific load to a capacitor bank when inductive loads have high-consumed power values. This method is beneficial when the active power rating for motor in Kw is 4 times the reactive power for the capacitor bank.

The main benefits for this method include:

- Helps to reduce the reactive power cost of extreme usage.
- Decreases the consumed apparent power.
- Cables with smaller cross-sectional areas can be used.
- Minimize the amount of copper loss in cables.

### 1.8 Compensation system

Other classification for capacitor banks can be related to the value of reactive power where it is constant or variable. The types of capacitors include:

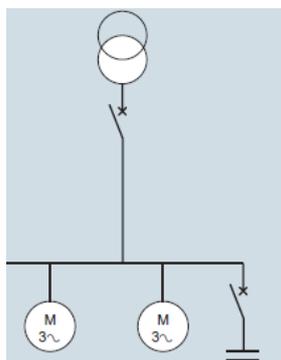


Figure 9: The mechanism for the fixed capacitors

### 2- Automatic type:

This type of capacitor is designed to produce variable values of reactive power depending on the operating load and the power factor. The capacitors can operate by different groups of capacitors connected in parallel using contactors. The

### 1- Fixed type

This type has a constant reactive power value even when the power factor value changes or remains the same. This means there is no possibility of acquiring a new Kvar value in case of changing the loads.

There are several ways to control this capacitance and including:

- Using a manual circuit breaker or load break switch.
- Capacitors can be switched by controller within a given distant.
- By connecting the capacitor with load and switching them as one unit.

These capacitors can be used in the following cases:

- Networks with loads will not change during the day.
- When there is a need to balance the total transformers reactive power.
- When using individual correction motors.
- Can be used when the total power of capacitor is 15% from the transformer power.

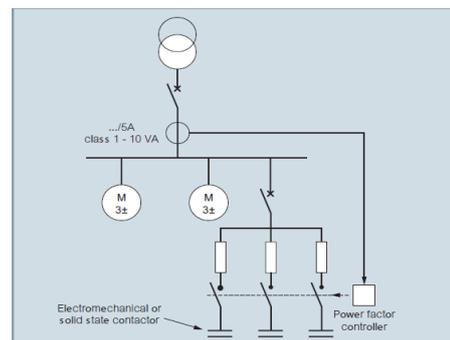


Figure 10: The automatic capacitor

switching is done for them by a power factor controller.

Automatic capacitors can be available in situations such as:

- When loads in the network change with time.

- Can be used to compensate the main bus bar for low tension board.
- If the reactive power for capacitor is greater than the power of transformer by 15%.

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