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Disseminate Technical Knowledge

Conserve Electricity

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Editorial

Dear Members,

Assalam-o-Alaikum We are sorry for delay in this number of the JOURNAL. The reason behind this was that we had been waiting for our Journal to acquire an "**ISSN**" number. We are very pleased to inform you that we have been successful in getting the ISSN number for the Journal: special thanks to Professor Dr. Suhail Aftab Qureshi for his strenuous efforts which made this possible. The ISSN number of the Journal is "**2226-3659**".

The **second** reason for the delay is our parallel efforts to get the New Horizon included in the list of the **Higher Education Commission'** approved journals. We have worked hard on this and the matter is under process at the HEC.

Yet another reason for this delay has been to select only the quality papers for the Journal. We are presenting to you the ten good papers which we have selected for this issue.

The Editor

A Review of Fault Detection in Transformers on the Basis of Trans-Admittance Analysis

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Abstract:

Insulation is considered an important and critical part of power and distribution transformers as any weakness of the insulation will result in the failure of these transformers. To ensure reliable operation of transformers in a power system, they are checked for their insulation integrity. For this purpose the transformers are undergone high-voltage impulse testing. In this test a standard 1.2/50 µs high-voltage impulse is applied and waveforms of voltage and current are recorded. In case of major faults there will be a considerable deviation between healthy and faulty waveforms so the detection of such faults is an easy task. It can be done by the visual inspection of the time-domain waveforms of the impulse voltage and neutral current. But in case of a minor fault e.g., a short circuit pbetween two adjacent turns of the winding, time domain waveform gives no useful information. To enhance the fault-detection sensitivity, impulse waveforms are analyzed in frequency domain. For this purpose many frequency response analysis techniques have been reported in the past few years. Analysis of only applied impulse voltage waveform does not help much in the detection of minor faults. So it is a common practice to analyze the applied impulse voltage along with the resultant current. The fault-detection sensitivity increases further if applied impulse voltage is analyzed along with the resultant current on the other side of transformer. In this research work a technique will be developed, based on the analysis of trans-admittance (ratio of primary current to secondary voltage in frequency domain), to detect and identify the fault in a distribution transformer.

Introduction

Electricity has become one of the fundamental resources of modern industrial society. Electric power is available to a user instantly, at required voltage and frequency and exactly in the required amount. To fulfill the ever increasing demand of electricity, the electric power is generated on a large scale far from the load centers. Then this power is transmitted over long distances through the transmission lines. For the purpose of the transmission of bulk electric power at large distances, voltage is stepped up to EHV to decrease the transmission line losses. This EHV is then stepped down to the distribution voltage levels near the load center. At the consumer end voltage is further stepped down according to the requirements. In this whole system, from generation to the distribution, voltage is transferred at different levels with the help of power transformers.

Transformers are an important part of power systems all over the world. So their protection and reliable operation is critical. Power systems are very complex due to the interconnection of a large number of generating stations, transmission networks and loads. Although an interconnected system increases the reliability of the whole system but it is also sensitive to the transients produced in the system due to switching and lightening. These high-voltage transients create a lot of stresses on the insulation of equipment such as transformers, generators, transmission lines etc.

Insulation is considered the most significant constructional element of a transformer. Any weakness in insulation strength can cause complete failure of a transformer. To insure reliable operation of transformers the detection of incipient faults is important prior to their installation in the system so that necessary corrective measures can be taken in time to prevent problems during their operation [2]. So they are tested for their insulation integrity. This level of insulation is also called the dielectric strength of the transformers' winding insulation.

To check this basic (lightening-impulse) insulation level (BIL) transformers are undergone for high-voltage lightening impulse testing. In this test initially a reduced impulse voltage is injected to the windings of the transformer under normal conditions and the waveforms of voltage and current are recorded. After that full standard 1.2/50 µs high voltage impulse is applied and impulse waveforms of voltage and current are recorded. Any deviation in the waveforms of both tests is an indication of a fault [3].

Literature Review

In past these waveforms were analyzed by visual inspection and comparison, and conclusions were drawn on the basis of experience of the inspectors. In case of a major fault there will be a noticeable deviation between healthy and faulty impulse waveforms, so older techniques can be adopted. But in case of minor faults e.g., a short circuit between adjacent turns time-domain analysis shows weak deviation between healthy and faulty conditions. So such faults cannot be detected by visual inspection of time-domain waveforms [1], [4]. To increase the fault detection sensitivity many transformation techniques have been adapted in the past few years. These techniques include frequency response analysis (FRA), transfer function method and wavelet analysis etc.

To obtain the transfer function of a transformer under test, the frequency response analysis (FRA) method has been used widely. In this method Fast Fourier Transform (FFT) is used as a standard technique [5], [6]. Although FRA method increases the fault detection sensitivity but the identification of minor faults is still a problem.

The investigation of transfer function of a transformer winding in the frequency domain is also used for the fault detection. Any damage in the insulation of a transformer will change its inherent parameters that will cause a change in its transfer function. So any weakness in the insulation integrity can be detected from the analysis of transfer function of a transformer [7]. The sensitivity of transfer function method with time-domain measurements of voltages and currents was sufficient in frequency range of 10 kHz - 1 MHz [1], [8].

The measurement of the admittance of a transformer at different frequencies can be used for the fault detection [8]. A transformer can be thought as a complex combination of winding resistance, inductance and capacitances (that comprise capacitance between turns, between turns of two different windings, between core and winding, between winding and the body of transformer etc.). The impedance of a transformer varies as a fault occurs in the transformer due to the weak insulation. The impulse wave has significant magnitude of all the frequency components between 10 kHz and 1 MHz, so this test can be used for the determination of admittance at wide range of frequencies. Winding admittance can be determined from the digitally recorded neutral current and high voltage applied during impulse tests.

Analysis of trans-admittance (the ratio of primary current to secondary voltage in frequency domain) considerably increases the sensitivity of fault detection as compared to the analysis of self-admittance (the ratio of primary current to primary voltage in frequency domain) because self-admittance has only one variable quantity as primary voltage remains almost constant. On the other hand trans-admittance has two variable quantities [8].

In the transfer function analysis technique, the fault detection sensitivity can be enhanced by using wavelet analysis instead of FFT when applying the impulse test [8]. The fault location can also be determined using wavelet transformation (WT) technique. In the frequency response analysis (FRA) time-domain information is lost but in wavelet analysis time-domain and frequency-domain information are available simultaneously. This time information is helpful to locate physical position of the fault in the winding of transformer [1], [9].

Expected Outcomes of the Study at UET Electrical Engineering

A research project is being undertaken at the Department of Electrical Engineering of UET, Lahore in which a technique, based on the analysis of trans-admittance, will be developed to detect and identify major and minor faults in a distribution transformer using the high-voltage impulse test. Trans-admittance will be analyzed by using transformation techniques and the results of these techniques will be compared with each other to get the best technique to achieve the required level of fault-detection sensitivity. For this purpose applied impulse-voltage waveform, primary current, secondary voltage and secondary current of transformer will be recorded by using a digital storage oscilloscope (DSO). To take the experimental results, an impulse generator (IG) will be used: this facility is available in the High Voltage Lab of the University of Engineering and Technology (UET), Lahore. A prototype of a distribution transformer, rated for 11 kV / 415 V, will be used for this research. In this transformer major and minor faults will be created to study their effects on the wave-shape and the frequency response of a high-voltage impulse.

Methodology

This project will be done in the following steps:

1. Detailed literature survey of different frequency response analysis (FRA) techniques and wavelet analysis techniques.
2. Modeling of an impulse generator (IG) in MATLAB SIMULINK.
3. Frequency analysis of impulse waveforms obtained from Simulink model and actual impulse generator.
4. Analysis of trans-admittance, obtained from the impulse testing, of a transformer in healthy conditions.
5. Analysis of trans-admittance, obtained from the impulse testing, of a transformer in different fault conditions.
6. Comparison and analysis of results to get a sensitive technique for the fault detection and identification in the distribution transformer.

Conclusion

The article reviews various techniques which can be used in the detection of faults within transformers. We are undertaking a project at the High-Voltage Engineering Laboratory of the UET Lahore in which we will be creating various faults within a distribution transformer and will study the possibility of identifying these faults on the basis of the determination of the transformer's trans-admittance. The recording of current and voltage within the transformer during impulse testing of the transformer will be the basis of this study.

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Quotations

- Knowledge of what is possible is the beginning of happiness.

  George Santyana

- Happiness lies not in the mere possession f money: it lies in the joy of achievement, in the thrill of creative efforts.

  Franklin D. Roosevelt

- History is the sole consolation let to the people, for it shows them that their ancestors were as unhappy as they are , or even more so.

  Sebatien Chamfort

- It is not love that is blind, but jealousy

  Lawrence Durrel

- Pains of love be sweeter for than all other pleasure are

  John Dryden

- The First duty of love is to listen

  Paul Tillich

- If you want to be loved, love and be lovable

  Benjamin Franklin

- 'Tis better to have loved and lost than never to have loved at all.

  Alfred, Lord Tennyson

- When love is suppressed, hate takes its place

  Havelock Ellis

- One is very crazy when in love

  Sigmund Freud

- Reason is a weak antagonist against love

  Madeleine de Scudery

- … Love without esteem cannot go far or reach high. It is an angel with only one wing

  Alexandre Dumas (fils)

- It is impossi ble to love and be wise

  Francis Bacon

- He that falls in love with himself will have not rivals.

  Benjamin Franklin

Eye Gesture Interpreter

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Abstract

Eye Tracking System has been in study for more than a decade now. Our project 'Eye Gesture Interpreter' works on the principles of Eye Tracking Technique. An algorithm has been designed in MATLAB for Iris recognition. It has been designed to aid the patients having limited movement of upper limb. It identifies the user's gaze on the screen by considering Iris as the circle and locating its position relative to the eye. We have designed individual GUI in MATLAB for the execution of algorithm which gives us the prototype for the desktop keyboard by providing three keys on the screen at the different corners. A MATLAB interfaced camera captures images, algorithm detects iris as the circle and the results are displayed on the screen. During the execution of algorithm the user was asked to look at any key and his gaze was then identified. Eye Gesture Interpreter has given us the cost effective and convenient method for Iris recognition technique.

Keywords—*Eye Tracking System, gesture, iris, prototype.*

1. BACKGROUND

Eye Tracking System is widely used to control several hardware and robotics. Our designed project, Eye Gesture Interpreter works on the principles of Eye Tracking Techniques. It translates the motion of the eye into an effective communication. It has a broad application in the field of Bio-Medical Engineering. Our project has been designed to aide physically disabled people by providing the prototype for the desktop keyboard.

2. INTRODUCTION

Eye Gesture Interpreter identifies user's gaze on the prototype keys drawn on the screen. An algorithm has been designed in MATLAB for the detection of user's gaze using Iris recognition technique. We have used Logitech's webcam to capture the user's image after a specific interval. A GUI has been designed for a desktop keyboard which has three keys drawn in different directions. The algorithm detects the gaze on a specific key and a corresponding message appears on the screen. There are two working modes of algorithm, manual and automatic. For the manual processing the camera has to be initialized for all iterations and for the automatic processing, the loop automatically runs for the specific number of iterations.

3. MATERIALS AND METHODS

Iris is a thin, circular structure in the eye which is responsible for the constriction and dilation of the pupil [1]. In the Eye Gesture Interpreter, Iris is assumed to be a circle, and the circle detection code is used to detect the circle for determining the user's gaze. The Eye Gesture Interpreter works in several steps. The user initially aligns his head with the two references. One of the references is the mark drawn on the computer screen with a marker and the other one is the static slider drawn on GUI. In order to make sure that eye is at the right distance from the camera, user has to fix his head relative to the references and run the process manually once. Figure 1 shows the GUI designed for the execution of algorithm. The push buttons, 'Start Camera' and 'Reference', are used to execute the algorithm manually and 'Process' is used for automatic execution. Text box is used to display the message. There are three other push buttons drawn on the three corners of GUI. They act as a prototype for keys.

For the manual execution, camera is initialized first by clicking on 'Start Camera'. After aligning head with the reference marks, the 'Reference' button is pressed and the code is executed. The image is captured upon which the edge detection is performed. The edge detected image is then converted from 2D array to 1D array. The circle detection code then identifies the iris as a circle and compares the coordinates of the circle with the pre-stored values. If the detected circle is incorrect or the results are not accurate then by increasing or decreasing the distance of the eye from the camera, algorithm can be executed again.

Once the algorithm has been executed manually and results are found to be accurate, the algorithm can be automatically executed by pressing 'Process' button. It will initialize the camera and would capture the images after a specified interval of time. The processing is performed automatically and the results are displayed for the fixed number of iterations.

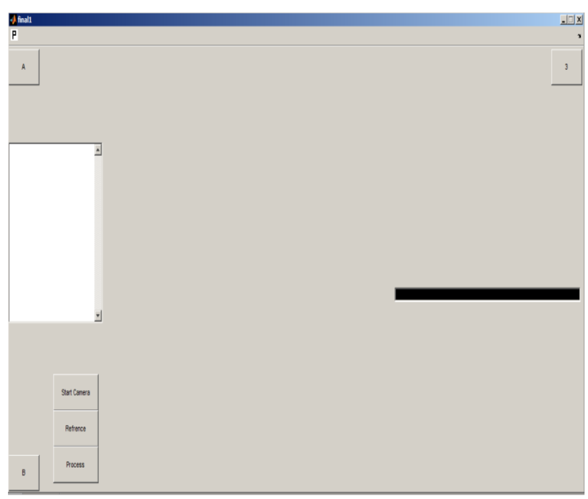

Fig.1 Designed GUI for Eye Gesture Interpreter. 'A', 'B' and '3' are the three prototypes for keys.

4. RESULTS

The designed algorithm was executed with the left eye. User was asked to gaze on the key ‘A’ and ‘Start Camera’ button was pressed. After aligning user’s head with the references, the ‘Reference’ button was pressed. The captured image appeared on the screen and then the gray scale image was displayed on the screen which had the detected edges, boundaries and the circle. The gray scale image was the cropped image as shown in Figure 2. The message ‘You are looking at A’ was displayed in the text box.

The user was then asked to look at the key ‘B’. It was made sure that the eye was fixed on the drawn mark but as ‘Reference’ was pressed, user blinked. The vague circle was detected and the message was displayed ‘You are looking at Wrong Direction’ as it is shown in Fig. 3. Although the circle was detected and appeared on the screen but as the coordinates of the circle were not in the range of the pre-stored values, the blink was detected as a wrong direction.

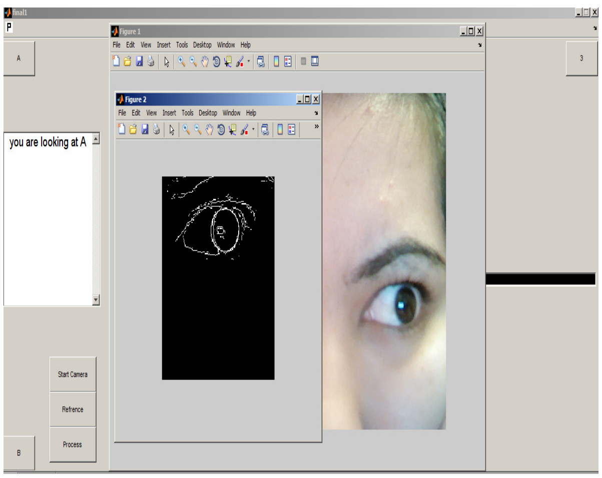

Fig.2 User was looking at key ‘A’. First image is the RGB image and the second image is the gray scale image on which circle detection was performed.

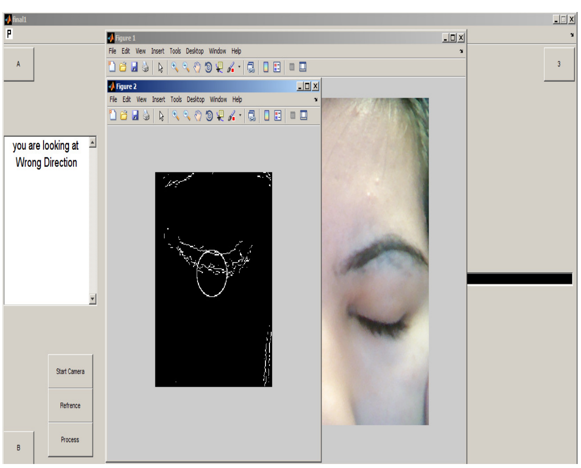

Fig.3 User was looking at ‘B’ and then he blinked. The gray scale image shows the blink of the eye.

The user was again asked to look at the key ‘B’. After making it sure that user was looking in the right direction, ‘Reference’ button was pressed. The results are shown in Figure 4. The iris was detected as the circle and the message ‘You are looking at B’ was displayed in the text box.

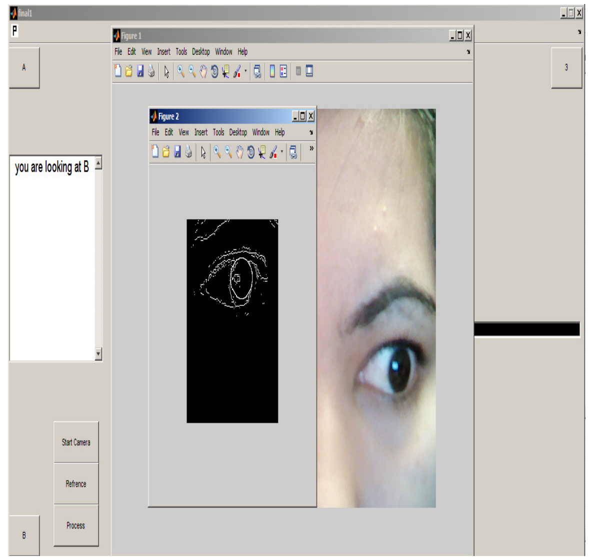

Fig.4 User was looking at ‘B’ and his gaze was identified.

This time the user was asked to look at ‘3’. While the eyes were in the right direction, the gaze was not identified and the circle was not detected at the right position. Results, shown in Fig. 5, appeared on the screen. Although the circle was detected but it was not detected on the iris, therefore; results were incorrect.

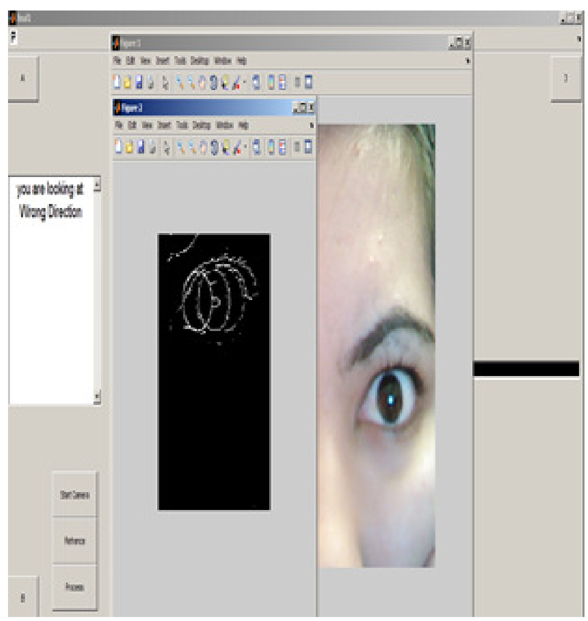

Fig.5 User was looking at ‘3’. His gaze was not identified in the correct direction.

The user was again asked to look at ‘3’. The ‘Reference’ button was pressed again. This time the iris was identified correctly. The obtained results are shown in Fig. 6.

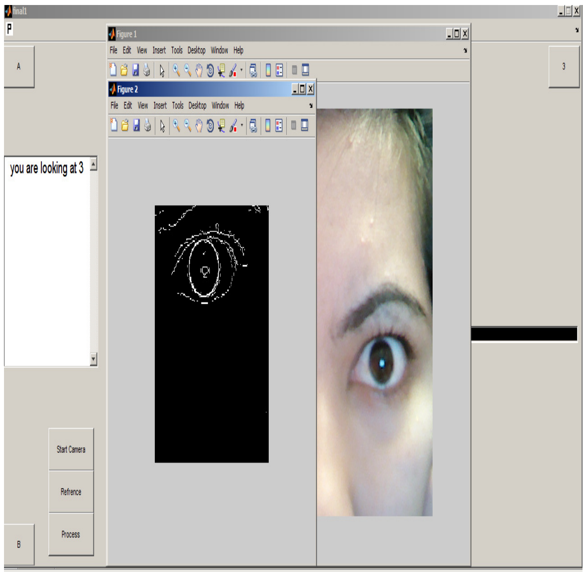

Fig.6 User was looking at ‘3’. Iris was recognized correctly.

5. CONCLUSION

The assay of the left eye with Eye Gesture Interpreter shows that although the software is not robust but it can be used as a prototype for the Eye Tracking System. Eye Gesture Interpreter gives us the desktop keyboard that can aid patients suffering from paralysis or other diseases resulting in limited movement of head and neck. This desktop keyboard currently has three keys but this work can be extended in future with further keys. Eye Gesture Interpreter has also proved effectively that Iris recognition technique with the webcam is cost effective and can be achieved easily. It does not need any head mounted device or the illumination of eye with Infra-red.

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N.E.C (U.S.A) and Space Around Electrical Equipment in Switchgear Rooms

By
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A.C.E (Pvt) Ltd

1. Introduction

In has been observed that in multi-storey Commercial Buildings owned by private persons, quite often, adequate working space around Electrical Equipment is not provided, though the same is required as per International Standards (such as IEC, BSS etc.). In these places often the electrical equipment, such as transformers, high voltage panels and low voltage panels etc. are installed in wedge shaped narrow areas or irregularly shaped areas and this practice is in contradiction to the recommendations of the above mentioned standards.

Further, at some commercial buildings it is observed that such a space around electrical equipment, which is in fact a "work space" is used as telephone operator's place or store items/cartons are placed in such areas which is all against the applicable clauses of the standards. Such practices are highly objectionable and should be discouraged by the authorities who have the jurisdiction (for example LESCO etc.).

So far as Government Owned Facilities (for instance Power Stations, High Voltage Grid Station etc.) are concerned, to begin with these do take into account the Standards but afterwards sometimes while expansion of the facilities is carried out, then new equipment is installed in the vicinity of the already installed one in an objectionable way.

This is a serious matter. The author happened to meet some electricians who got injured as the space around the electrical equipment was quite inadequate so they could not step back when due to some faults the electrical sparking started in the panels.

National Electrical Code of U.S.A (Ref. 1) can help us a lot in this regard since it has dealt the topic in detail in Section 110-26 of the Code. In this paper this very important issue has been treated in an exhaustive way.

NEC is much superior to IEC and some other International Standards in one respect that it is complete and self contained, while in the case of the latter when you refer to one IEC standards, it will give reference of nearly ten other IEC standards and an individual who does not have a complete Library of IEC Standards is stopped in the middle as he does not have all relevant IEC standards.

2. National Electrical Code (U.S.A)

The National Electrical Code (abbreviated as NEC) is one of many codes and standards that are published by the National Fire Protection Association (NFPA), a not-for-profit corporation. The First Edition was issued during the year 1896. The code is revised every three years in order to keep up with new materials, tools, and methods that are constantly being developed. This work is performed by 21 separate committees, each consisting of approximately 10 to 15 persons, the majority of them engineers. Members of each committee meet several times, discuss all proposed changes, accepting some and rejecting others, and rewrite (as required) the sections of the Code that were assigned to their committee. Then, they circulate the changes among the various committees, coordinate the changes, and rewrite again. So, obviously, the updating of the NEC is a tedious task. But the real difficulty is that it must remain applicable to all types of electrical installations, leaving no "gaps". Because of this, it becomes rather difficult to interpret in some instances. For this reason, Handbooks are also available which are written by prominent and experienced persons and these Handbooks are very useful.

The engineers who write the Code and the Handbooks are deeply concerned with technical accuracy and completeness.

NEC is being used not only in U.S.A but also in some other countries such as Saudi Arabia and Kuwait etc.

In Saudi Arabia historically the Eastern Region has more American influence due to the presence of ARAMCO which has been carrying out the trade of crude oil for the past 80 years. The author happened to see some contracts regarding Thermal Power Plants which were awarded by SCECO East (now it is called S.E.C) and which contained reference of above said NEC. In Dammam area, sockets, switches and wiring devices are generally in accordance with N.E.C (U.S.A).

In view of its usefulness, it is urged that WAPDA and NTDC should also start including applicable parts of NEC Code in their future Electrical Contracts.

3. Important Clearances

In a switchgear room, we come across many metal-clad switchgear enclosures and steel panels. Metal-clad switchgear can be draw out type or fixed type. Further the metal-clad switchgear can be 11kV type (or sometimes even 33kV) or it can be low voltage (L.V) type.

So far as L.V panels are concerned, various versions are available. There are some panels which have a front door for opening these. All the equipment and meters installed in these can be approached from the front side. Since the back side of such a panel need not be opened from the back side, therefore, such panels can be even installed against the wall of the room.

However, some time it is required to open a panel from the hinder side (for example, some incoming/outgoing cables are to be fitted in that portion). In such a case, work space has to be provided not only in the front side of the panel but also at its back side.

NEC has recommended work spaces for the various possible cases. For example, it indicates the same for the following cases:

(i) What is the depth of working space which is required when only the front door of the panel is to be opened? In this case, the back door is permanently closed.

(ii) What is the depth of working space which is required when both, the front door of the panel as well as its backdoor, need to be opened for electrical testing or maintenance?

(iii) What is the depth of working space which is required when the front door of the panel needs to be opened for electrical testing or maintenance but its back side door may need to be opened for some non-electrical activity?

(iv) What is the depth of the working space which is required in front of the electrical equipment? NEC provides this information

(v) NEC also dictates that doors on all electrical equipment must be capable of opening to at least a 90-degree angle.

(vi) NEC also states that no equipment is permitted to extend more than 6 inches (i.e 150 mm) in front of another piece of equipment. For instance, a large transformer may not be placed in front of a switchboard (or panel board) even when the top of the said transformer is lower than the bottom of the switchboard.

(vii) Above and below every electrical equipment (i.e panel etc.) there is some dedicated space. NEC provides this information in detail.

(viii) In the electrical switchgear room, how many doors need to be provided. NEC also provides detail as to how much should be the width and height of such a door.

All the above mentioned points are discussed in detail in the following text.

4. Working Space

Every electrical equipment (for example a control panel, a distribution panel, a transformer or a motor control centre etc.) must have adequate working space for maintenance or operation purposes.

National Electrical Code of U.S.A, abbreviated as NEC, has many Articles wherein this subject is stated. So far as the equipment whose rated voltage is 600 volts or less is concerned, it is stated in Article No. 110.26. The following is stated:

"Working space for equipment operating at 600 volts nominal or less to ground and likely to require examination, adjustment, servicing or maintenance while energized shall comply with the dimensions of 110.26 (A) (1), (2) and (3) or as required or permitted elsewhere in this code".

Article 110.26 (A) (1) sate the following:

"(1) The depth of the working space in the direction of live parts shall not be less than that specified in Table 110.26 (A) (1) below. Distance shall be measured from the exposed live parts (i.e. energized parts) or from the enclosure or opening if the live parts are enclosed in some panel or box.

Table 110.26 (A) (1) Working Spaces

Nominal Voltage to Ground (Volts)	**Minimum Clear Distance**		
	Condition 1	**Condition 2**	**Condition 3**
0-150	900mm	900mm	900mm
151-600	900mm	1.0m	1.2m

Condition 1: Exposed live parts (or metallic enclosure of those live parts) on one side and no live or ground parts on the other side of the working space. Live parts on both sides effectively guarded by suitable wood or other insulating material (for example, thick plastic sheet is fixed on the wall with insulated nails).
Refer to attached Figure No. 1.

Condition 2: Exposed live parts on one side and grounded parts on the other side. It should be borne in mind that a concrete wall or a brick wall is considered as grounded.
Refer to attached Figure No. 2.

Condition 3: Exposed live parts on both sides of the work space (not guarded as provided in condition 1 above).
Refer to attached Figure No. 3.

In Pakistan, the low voltage distribution system generally is 230 volts single phase and 400 volts three phase. In view of this, generally 151-600 volts category, as given in Table No. 110.26 (A) (1) above, can be employed in Pakistan. However, some time we come across 110 volts battery system which have 110 volts d.c. distribution panels. In such places 0-150 volts category shall be applicable.

Refer to attached Figures No. 1 to 3 wherein the various conditions are illustrated and explained in detail.

5. Access And Entrance To Working Space

"Access" and "Entrance" refer to the actual working space requirements, not to the room (where the panels are installed) itself. However, in instances where the electrical equipment is located in tight portions of a small room, the working space could in fact be the entire room.

For an electrical room in which a panel or a group of panels (or similar electrical equipment such as transformers, batteries etc.) is installed, there must be one entrance, such as a door, whose length and width should not be less than 6.5 feet (i.e. 1950 mm) and 2.5 feet (i.e. 750 mm) respectively. Refer to Figure 4 where it is explained in some detail. However, if the above said electrical equipment is having a current rating of 1200 A or more and at the same time the length of the equipment is 6 feet (i.e. 1800 mm) or more, then there must be two entrances, one on each side of the equipment. Refer to Figure 5 where it is explained in more detail. NEC Code further explains that it is possible to have only one entrance even for the above mentioned equipment having a current rating of 1200 A or more, provided the following two conditions are met:

(a) Working space, which is required as per Table 110.26(A) (1) is doubled in the direction of "Access" to the equipment.

(b) The entrance door is located in such a way that continuous and unobstructed means of egress are available.

6. Working Space "Width"

For equipment less than 30 inches (i.e. 750 mm) wide, a working space width of not less than 30 inches (i.e. 750 mm) should be provided. This will enable a person to stand and work conveniently on the equipment. Refer to Figure 6.

For equipment 30 inches (750 mm) wide or greater, provide working space width of not less than the width of the equipment. This will enable an operator to stand anywhere in front of the equipment. Refer to Figure 7.

7. Working Space "Height"

When the height of the equipment is less than 6.5 feet, clear and unobstructed working space height in the direction of

"access" to the equipment must not be less than 6.5 feet (i.e. 1950 mm). Suppose you have an equipment whose height while standing on the floor is merely 4 feet (i.e. 1200 mm). Even then you must provide 6.5 feet of "Working Space Height" in front of the said equipment. This means that you cannot put electrical equipment in some room whose height from floor to ceiling is less than 6.5 feet (1950 mm).
However, when the height of the equipment is more than 6.5 feet then the minimum height of the working space must be equal to the height of the equipment.

8. Dedicated Space Above The Electrical Equipment

In addition to the "Working Spaces" discussed above, there must be some dedicated spaces above and below the electrical equipment which must be provided. For example take the case of a surface mounted circuit breaker panel. Suppose this panel is 1 foot (300 mm) wide and 2 feet (600 panel is say 1 foot (300 mm). As per NEC the height of the dedicated space above the panel shall be 6 feet (1830 mm) or upto the structural ceiling whichever is lower. So the "Dedicated Space" above the panel shall be equal to the width and depth of the equipment and extending upto 6 feet above the panel when the height of the "structural ceiling" is say 7 feet (2100 mm) above the panel. So far as the dedicated space below the panel is concerned, we must provide dedicated space from the floor level upto the beneath side of the panel. So far as the width and depth of such a dedicated space is concerned, it shall be as before i.e. equal to the width of the panel as well as depth of the panel.
In the above mentioned dedicated space, nothing which is not related to the above said equipment shall be allowed. For example a "lighting fixture" or an Air Inlet Duct etc. will not be allowed. However cables and conduits which are entering the panel are allowed to be installed in such a dedicated space.

9. Illumination

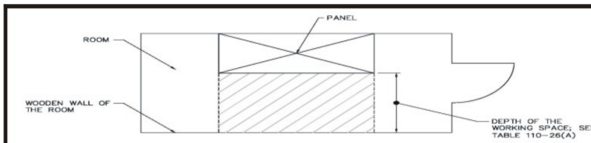
Provide illumination for all working spaces around service equipment, switchboards, motor control centres and transformers etc. The required illumination shall not be controlled by automatic means only (motion sensors) as this would introduce a hazard. For example if the person working on the equipment did not physically move around enough to keep the motion detector's sensor in the "on" position, then the lights would shut off. NEC Code does not specify as to how much illumination is required. In this context IES relevant publications should be consulted.
Further it should be borne in mind that the lighting fixtures should not be installed in the Dedicated Space which is explained in the preceding paragraphs. However, it can be installed in some location which is adjacent to the above said Dedicated Space.

10. Conclusion

Adequate work space for safety must be maintainedfor easy maintenance of electrical equipment (such as Distribution Panels, Motor Control Centres etc.). Many electricians have been badly injured due to inadequate work space.
NEC has given recommendations in this regard. Table 110-26 (A) (1) of the above said NEC, indicates depth of the work space as well as width of the working space regarding equipment. The above mentioned Table has been included in this paper.
Further, number of entrances in a switchgear room as well as height and width of the entrance door etc. are indicated.
In addition to above, there are dedicated spaces which must be provided above as well as below a panel. The dimensions of the dedicated spaces are indicated.
In view of its usefulness, it is urged that WAPDA and NTDC should also start including applicable parts of NEC Code in their future Electrical Contracts.

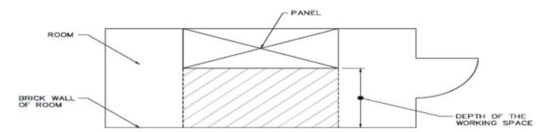
References

Ref. 1: National Electrical Code, Year 2008 Edition, published by National Fire Protection Association, U.S.A.



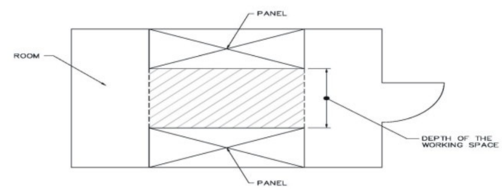
ABOVE FIGURE SHOWS CONDITION-1, FOR 151-600V PANELS, DEPTH OF WORKING SPACE=900mm

FIGURE-1



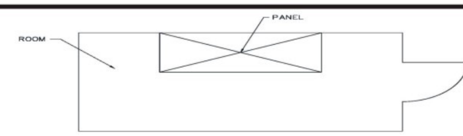
ABOVE FIGURE SHOWS CONDITION-2, FOR 151-600V PANELS, DEPTH OF WORKING SPACE=1050mm

FIGURE-2



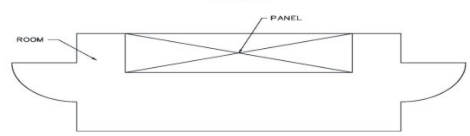
ABOVE FIGURE SHOWS CONDITION-3, FOR 151-600V PANELS, DEPTH OF WORKING SPACE=1200mm

FIGURE-3



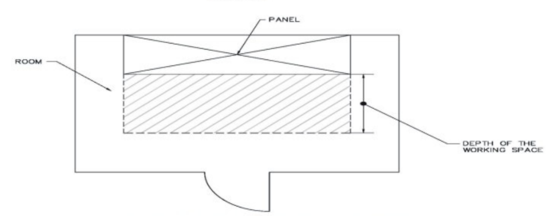
FOR PANELS OF LASS THEN 1200A, ONE DOOR (6.5 feet high x 2.5 feet wide) MUST BE PROVIDED

FIGURE-4



FOR PANELS OF 1200A OR MORE, TWO DOORS (each 6.5 feet high x 2.5 feet wide) MUST BE PROVIDED

FIGURE-5



FOR PANELS OF 1200A OR MORE, ONE DOOR IS ALLOWED PROVIDED THE DEPTH OF WORKING SPACE IS MADE DOUBLE.

FIGURE-6

Enhancement in Power Transmission System Using Statcom & SVC Facts Controllers (Part-I)

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Elect. Engg. Deptt. UET, LHR.

1. INTRODUCTION

Electricity supply industry has been facing problems in the past many years to achieve the high level performance due to increasing demands. Upgrading of existing power plants, installation of new power plants, environmental effects, deregulation and development of fast-response electronic control devices are the major part of these demands.

Lack of experienced power engineers in the field of Generation, Transmission and distribution affected the design work in electric power systems. Design work depends on various areas of expertise, disciplines, simulations, data and real examples. The single document does not contain all this knowledge, but it is widely scattered. Most of it exists in the mind of human experts. This part of the paper contains the details about the FACTS Device, Particularly STATCOM & SVC type.

The major concerns of the power system operators are the voltage stability and efficiently voltage alteration. It is the ability of the power system to maintain allowable voltage limits at all nodes in the system under normal and emergency conditions. Continuous and unmanageable decrease in voltage may lead to voltage instability condition in a power system. Voltage instability arises due to insufficient reactive power supply from generators and transmission lines.

In order to avoid equipment failure due to the unstable voltage, efficient control is required at all the main point of the network, as transmission of active power requires also requires magnitude of the voltage high enough to support the loads. To control the voltages in a power system, different techniques are used. The paper accentuates the role of two shunt connected FACTS controllers i.e. STATCOM & SVC in regulating the system voltage and improving the overall performance of the system.

2. OBJECTIVE OF THE RESEARCH

The objectives of the research are as follows:

1. Study of Power Transmission System & their constraints.
2. Study of Shunt connected FACTS devices i.e. STATCOM & SVC.
3. Application of STATCOM & SVC in a typical power system under heavy loading & fault conditions so as to provide the voltage regulation by generating reactive power.
4. Modeling of the power system with STATCOM & SVC using Simulink Software.
5. Comparison of STATCOM & SVC in enhancing the performance of the overall power system.
6. Simulation Part of this paper will be presented in Part II of this paper.

3. PROBLEM STATEMENT

The overall objective of this thesis is to study the behavior of Shunt connected FACTS devices i.e. STATCOM & SVC so as to provide the voltage regulation under heavy loading and fault conditions by generating reactive power at the point of its connection.

4. FACTS DEVICES

4.1 BACKGROUND OF TRANSMISSION LINES

Three main features of the electric power transmission are: Generation, Transmission and Distribution. Due to the rapid expansion and growth of electrical utility industry, frequent changes are continuously brought in to a final conventional product. Electricity due to the involvement of high level engineering is increasingly considered as a product. As a result transmission systems are overloaded to their stability and thermal limits. However, there are certain limitations on the transmission systems like power transfer between areas or within a single area [1].

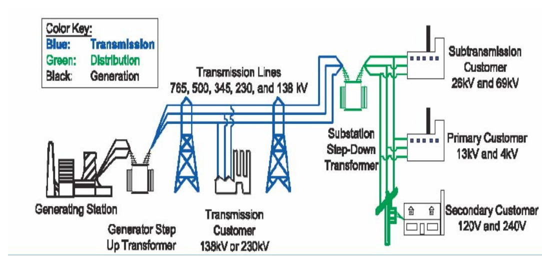


Figure-1: A typical Power System [1].

4.1 CONSTRAINTS OF TRASMISSION LINES

There are certain limitations on a transmission system that cannot be neglected in any case:

- Steady-State Power Transfer Limit – Stability problems at energy transfer over long transmission distances.
- Voltage stability limit – Voltage control at various loading and fault conditions.
- Dynamic voltage limit.
- Transient stability limit.
- Power system oscillation damping limit – Reactive power balance (voltage transmission losses).
- Unintentional loop flow limit.
- Thermal limit.
- Short circuit current limit – Increase of short circuit power in meshed systems.

Now there are certain conventional techniques available to control these constraints as shown in the table-1 below: **[2].**

Due to high cost, less favorability and heavy construction, these conventional techniques are no more trustworthy. To have operational as well as financial profitability the existing transmission system is required to be more efficiently controlled and utilized. In past, the conventional ways of upgrading the transmission system with new transmission lines was very difficult, expensive and time consuming.
The technology of conventional methods has to enhance a flexible and worst generation capable transmission system. It is of vital importance to utilize the transmission line in an economical manner enabling industrial utilities to remain aggressive and to carry on. The investment in transmission system for its optimal utilization is also important to support industry, create employment and utilize economic resources in the developed countries.

Conventional Transmission Enhancement Techniques	**Impedance control**	**Voltage control**	**Angle control**	**Power Control**
Series Capacitor	✦			
Shunt Capacitor & Reactor		✦		
Transformer Load Tap Changer			✦	
Phase Shifting Transformer			✦	
Synchronous Condenser		✦		

Table-1: Conventional Techniques of Enhancement in Transmission System [2].

To enhance the performance of the existing power system through advanced control technologies and to fulfill all the power demands, flexible ac transmission system (FACTS) is not only a cost effective solution, but proven solution to the way the transmission systems are controlled and developed.

5. FACTS CONTROLLERS

FACTS devices are the latest technology of power electronic switching devices used for the dynamic voltage control, impedance control, angle control and power control of the transmission lines. Based on the power electronic devices used, there are two types of FACTS controllers: **[3].**

- Thyristor based controllers
- Converter based controllers

Thyristor based FACTS controller includes:
- Static VAR compensator (SVC)
- Thyristor controlled series capacitor or compensator (TCSC)
- Thyristor controlled phase angle regulator (TCPAR)

The first two controllers SVC & TCSC are the major members of this group. Both these controllers employed capacitor or reactor banks, alongwith thyristors as switching elements used to control the reactive impedance by generating or absorbing the required reactive power.
TCPAR do not use any inbuilt capacitor & reactor, but may use for the reactive power support to AC system. As a result, SVC & TCSC present variable reactive impedance indirectly to the transmission system. SVC is a controlled shunt reactive admittance source in which the required reactive current is a function of the system voltage. TCSC is controlled reactive impedance in series with the line in order to develop the compensating voltage i.e. required voltage is a function of line current. Both the controllers do not exchange real power with the AC system. Fig.2 below indicates the application of thyristor based controller in a power system: **[3].**
Converter based FACTS controller includes:

- Static synchronous compensator (STATCOM)
- Static synchronous series compensator (SSSC)
- Interline power flow controller (IPFC)
- Unified power flow controller (UPFC)

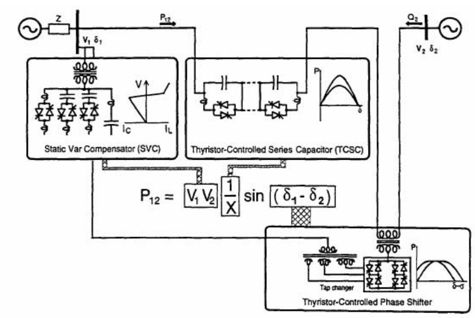


Figure-2: Thyristor based controllers [2].

The converter based FACTS controllers consist of self-commutated, voltage source converters. It is a new generation of transmission controllers. These controllers can provide reactive shunt & series compensating current and voltage, independent of the ac system voltage and current respectively. In addition to controllable reactive power compensation, these controllers can also exchange adjustable real power with the system. A typical application of converter based controllers is as shown in the fig.3 below: **[2]**

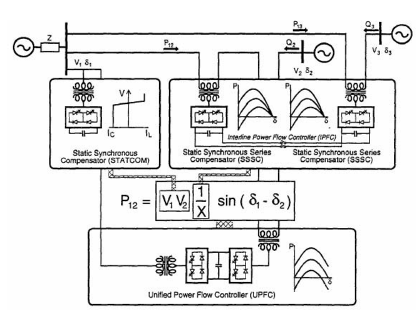


Figure 3: Converter based controllers [2].

So instead of constructing a new transmission line, FACTS controllers can improve the opera-tion of new transmission lines with minimum cost investment, minimum time and minimum environmental affects. FACTS devices can be further classified as shunt, series and shunt-series connected devices as given below: **[3].**

5.1 Shunt Connected:

- Static VAR Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- Static Synchronous Generator (SSG)
- Superconducting Magnetic Energy Storage (SMES)
- Static VAR System (SVS)
- Static VAR Generator or Absorber (SVG)
- Static Condenser (STATCON)
- Thyristor Switched Reactor (TSR)
- Thyristor Switched Capacitor (TSC)
- Thyristor Controlled Reactor (TCR)
- Thyristor Controlled Breaking Resistor (TCBR)
- VAR Compensating System (VCS)

5.2 Series Connected:

- Thyristor Switched Series Reactor (TSSR)
- Thyristor Controlled Phase Shifting Transformer (TCPST)
- Static Synchronous Series Compensator (SSSC)
- Thyristor Controlled Series Capacitor (TCSC)
- Thyristor Controlled Series Reactor (TCSR)
- Thyristor Switched Series Capacitor (TSSC)

5.2.1 Shunt-Series Connected:

- Unified Power Flow Controller (UPFC)
- Interphase Power Flow Controller (IPFC)

The table-2 below indicates some of the FACTS devices w.r.t. their involvement in power system enhancement. **[2,3]**

The more commonly used FACTS devices are as follows: **[4]**

5.3 Static VAR Compensator (SVC)

It is the first generator of the FACTS family and a shunt connected device. It provides the steady state and transient voltage control by reactive power exchange with the system. It is also used to reduce power swings, flickering and reactive power compensation.

5.4 Static Synchronous Compensator (STATCOM)

STATCOM is a fast response FACTS device comprised of GTOs (Gate turn off thyristors). It provides the dynamic voltage control by reactive power exchange independent of the AC system voltage. It can be based on a voltage source as well as current source converter.

FACTS Devices	**Impedance Control**	**Voltage Control**	**Angle Control**	**Power Control**
Static Synchronous Compensator (STATCOM)		✦		
Static VAR Compensator (SVC)		✦		
Unified Power Flow Controller (UPFC)	✦	✦	✦	✦
Convertible Series Compensator (CSC)	✦	✦		
Interphase Power Flow Controller (IPFC)	✦	✦	✦	✦
Static Synchronous Series Controller (SSSC)	✦		✦	✦
Thyristor Controlled Series Capacitor (TCSC)	✦			

Table 2: Type of FACTS Devices w.r.t. to operation [2].

5.5 Thyristor Controlled Series Capacitor (TCSC)

TCSC is used to control the power flow, damping of power oscillations and increase of energy transfer with the help of series capacitor in parallel with controlled reactor. It is an excellent source of series compensation [4].

5.6 Unified Power Flow Controller (UPFC)

UPFC is actually a combination of static synchronous compensators (SSSC) & (STATCOM) with a common DC capacitor. By means of series voltage injection, it is able to control line impedance and active & reactive power flow through the transmission line [4].

6. STATIC SHUNT COMPENSATION

Static shunt compensators are used to control the voltage of the transmission line by injecting reactive current at the point of its connection. The impedance of the shunt controller is the main cause of the variable reactive current flow in the line. The shunt controller only supplies or absorbs variable reactive power as long as the injected reactive current is in phase with the line voltage. The major objective of the shunt compensators is to increase the capability of the power to be transmitted from generation to load end in order to make the system stable [4].

6.1 Static Shunt Compensators – Principle of operation

In a practical power system, most of the loads are normally inductive which are the main sources of reactive power. The energy alternately stored or released by the inductors and capacitors are known as reactive power. Reactive power directly affects the system voltages and is the cause of unstable system. The transmittable electric power of the system is defined by the following equation: **[2,4]**

$$P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2) \text{ ----------------------- (1)}$$

in which

V_1 is the magnitude of sending end voltage
V_2 is the magnitude of receiving end voltage
δ is the phase angle between V_1 and V_2
X is the system impedance

The diagram of the equation is as shown in the fig.4 below:

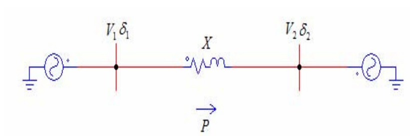


Figure 4: Power Flow Scheme.

The basic principle of the static shunt compensator is to generate reactive power by using a voltage source converter similar to that of a conventional rotating synchronous machine as shown in the fig. 5 below: **[2,4].**

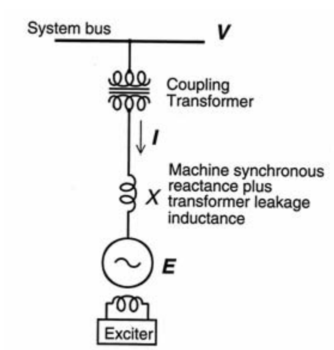


Figure-5: Reactive Power generation by a rotating synchronous compensator [2].

The function of a voltage source converter is to convert DC voltage from the capacitor into three phase AC voltage. Recall the operation of a rotating synchronous machine in which for pure reactive power flow, induced three phase emfs are in phase with the system voltages. The machine draws reactive current from the system which is dependent on the system voltage V, excitation voltage E of the machine and its reactance and transformer leakage reactance plus system short circuit reactance. The expression is as shown below:

$$I = \frac{V - E}{X} \text{ -----------------------(2)}$$

The reactive power exchange can be expressed as follows:

$$Q = \frac{(1 - E/V)\, V^2}{X} \text{ ------------- (3)}$$

The flow of the reactive power can be controlled by the excitation voltage of the machine (E) comparative to the system voltage (V). Increasing amplitude of E above V will make the machine operating an over excited condition resulting into a leading current and capacitive mode of the machine. Decreasing E below V will make the machine operating in an under excited condition resulting into a lagging current and inductive mode of the machine, Thus the shunt compensation is used to control the voltage of the transmission line by generating or absorbing capacitive and inductive current respectively in order to maintain the system disturbances and emergency conditions. Basically the requirements for the compensation are of two types: **[5].**

1. **Direct voltage control** – to maintain the system voltage under heavy loading conditions.

2. **Transient & Dynamic voltage control –** to maintain the system voltage under fault conditions and to provide the power oscillation damping.

Static Shunt Compensators – Major requirements

Shunt compensating devices have the following major requirements: [2]

1. Static synchronous compensator should be able to deal with all kind of situations like major disturbances in the form of faults etc at the bus of the AC system to which it is connected to provide the shunt compensation. In case of any nearby fault causing drastic decrease in bus voltage, the static synchronous compensator must be able to restore the bus voltage immediately after fault clearance.

2. Static synchronous voltage should be able to regulate the bus voltage by injecting or absorbing reactive power as required by the system conditions in order to improve transient stability and power oscillation damping.
   Hence the shunt compensation provides the following main operations:

   1. Reactive power control of dynamic loads
   2. Steady State and dynamic voltage control
   3. Damping of active power oscillations
   4. Improvement of system stability

6.2 Static Shunt Compensators – Application

Shunt compensation technique is the backup to the defects in the series technique, mostly in the voltage control because of its location in a system. Table below indicates the applications of some different type of shunt compensators w.r.t. the corresponding short circuit level and the transmission phase angle. **[2,4]**

Mechanically switched reactor (MSR) and Mechanically switched capacitor (MSC) devices also belong to the shunt compensation family. Table clearly shows that STATCOM & SVC are better in performance as compared to the other devices **[5]**.

7. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM is an advanced version of shunt connected SVC and has a faster response than SVC in regulating system voltage by generating capacitive & absorbing reactive current independent of the AC system voltage. This is because in the event of sudden change in the system voltage, the capacitor voltage does not change instantly. Thus STATCOM is very effective in cases where immediate response is required for the desired changes. **[1,2,4].**

STATCOM consists of voltage source converter with self commutated semiconductor devices such as GTOs, IGBTs, IGCTs, MCTs etc. This makes the STATCOM much capable of high dynamic performance as compared to SVC with controllable reactors and switched capacitors. **[4]**

Major advantages of STATCOM over SVC are:

1. Faster Response
2. Less in size & weight
3. Inherently modular & re-locatable
4. Cost reduction
5. Active harmonic filter capability
6. It can be interfaced with real power sources such as battery, fuel cell etc.
7. It can provide maximum capacitive & inductive current at any system voltage.

Previously the STATCOM was called as Static synchronous condenser (STATCON) due to the same principle of operation.

7.1 CONFIGURATION OF STATCOM

STATCOM is comprised of three main parts as indicated in the fig.6 below: **[1,2,4].**

- Voltage Source Converter (VSC)
- Coupling Transformer.
- External Controller

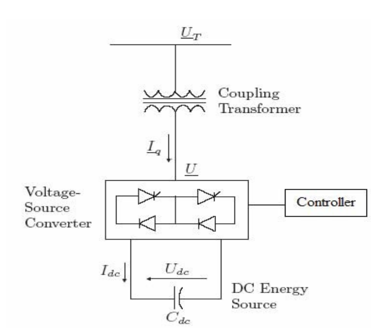


Figure 6. Configuration of STATCOM [2].

A voltage source converter is used to convert the DC voltage of a capacitor into three-phase AC voltage with the help of GTO (Gate turn-off) switches i.e. the magnitude of the voltage can be controlled by controlling the firing angles of the GTOs. A three phase, three pulse VSC is as shown in the fig. 7 below: **[2].**

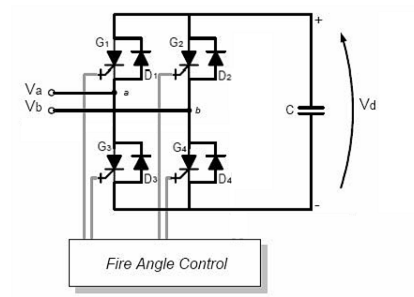


Figure 7. Three-Pulse Voltage Source Converter [2].

The configuration consist of three GTOs connected anti-parallel diodes with a DC source probably the small charged capacitors.

A coupling transformer is used to connect the VSC to the AC power system. The leakage reactance/inductance of this transformer is used to filter the current harmonics normally generated due to the energy stored in the capacitor and pulsating output of the VSC.

The function of external controller of the STATCOM is to synchronize the converter output voltage with the system voltage in such a way so that the STATCOM generates or absorbs required reactive power at the point of its connection [2].

7.2 BASIC OPERATING PRINCIPLE OF STATCOM

Refer to the fig.8 below:

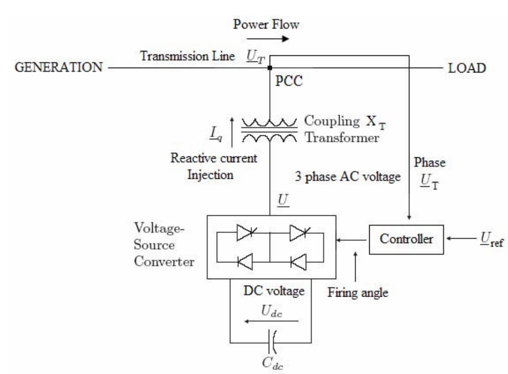


Figure 8. Operating Principle of STATCOM [1].

A power system shown has a deregulated voltage due to which a STATCOM has been shown connected at the point P through a step up coupling transformer. The external controller of the STATCOM is controlling the firing angle of the switching GTOs of the converter to control the magnitude of the converter output voltage. A STATCOM is a controlled reactive power source by generating or absorbing the reactive power at the point P **[1].**

The charged capacitor C_{dc} produces the DC output voltage V_{dc} to the converter which then produces a set of controllable three phase output voltages V. The voltages V are in synchronism with the AC system voltages performed by an external controller. The controller is actually performing the matching of the voltage V_T with V_{ref} by controlling the firing angles of the converter. The voltage V_{ref} is set manually to the controller. I_q is the reactive current injected by the STATOM into the system which is actually the current produced from the capacitor by absorbing real power from the AC system. The expression of the reactive current is as follows: [1, 2].

$$I_q = \frac{V_T - V_{eq}}{X_{eq}}$$

Where:

I_q = Reactive current injected by the STATCOM
V_T = Terminal voltage of the STATCOM
V_{eq} = Equivalent thevenin voltage seen by the STATCOM
X_{eq} = Equivalent thevenin reactance of the system seen by the STATCOM

Mode of STATCOM will be capacitive in case reactive power is generated and a leading current is produced i.e. this is the case when amplitude of the voltage V is greater than the system voltage V_T. Conversely, if amplitude of the voltage V is less than the system voltage V_T STATCOM mode will be inductive, lagging current will be produced and reactive power will be absorbed. If amplitude V is equal to V_T, no power exchange will occur. **[2, 4].**

Like any other electrical device, a practical converter also has some internal losses i.e. it is not lossless. These appear as the energy stored in the DC capacitor. To balance these losses, a small amount of active power has to be absorbed from the system. This can be done by making output voltage of the converter slightly lags the system voltage by an angle δ. [2]

The four quadrant phasor diagrams of the STATCOM operation are as shown below in fig. 9:

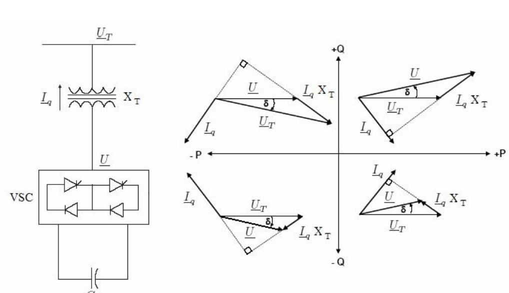


Figure 9. Phasor Diagram of STATCOM [2].

A battery can also be used as a DC source instead of capacitor. Which then make the converter able to control reactive as well as active power. This could be very useful in the cases where control of active power flow is required and to damp the power oscillations in the system **[2].**

CHARACTERISTICS OF STATCOM

The two modes of operation of STATCOM are: **[1]**

1. Voltage regulation mode
2. VAR control mode

In voltage regulation mode, STATCOM has the following V-I characteristics:

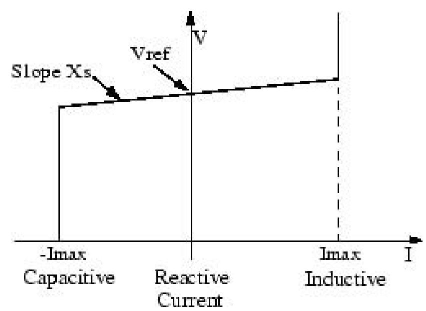


Figure 10. V-I Characteristics of STATCOM [1].

$-I_{max}$ Capacitive & I_{max} Inductive indicates the maximum and minimum values of the reactive currents. Now as these currents are within the range as shown in the characteristics above, voltage will remain regulated at the reference voltage V_{ref}. The slope Xs can be adjusted within 1% to 4%. In voltage regulation mode, the V-I characteristics of the STATCOM can be defined with the following equation: **[1].**
$V = V_{ref} + X_s.I$

Where:

V = System Voltage
I = Reactive current of the STATCOM
X_s = Slope reactance
V_{ref} = Reference voltage to the converter

From the characteristics it is quite clear that STATCOM can maintain the full reactive current independent of the system voltage.

7.4 APPLICATION OF STATCOM

Typical application of the STATCOM can be found in utilities with weak grid loops or having fluctuating reactive loads. However some other applications are as follows: **[1, 2].**

1. Unbalanced loads
2. Arc furnaces

3. Wind farms (normally use induction generators of low Power factor against which a STATCOM can be used to improve both steady state and dynamic characteristics of the wind network)
4. Wood chippers
5. Welding operations
6. Car crushers
7. Industrial mills
8. Mining shovels
9. Harbor cranes

Further the application of STATCOM is found to prevent damaging of over-voltages that may occur due to isle conditions.

7.5 ADVANTAGES OF STATCOM

The main advantages of the STATCOM are: [1,2].

1. Continuous & dynamic voltage control
2. High dynamic & very fast response time (the response is much faster to changing system conditions)
3. Enables grid code compliance
4. Maximum reactive current over extended voltage range
5. High efficiency
6. Single phase control for unbalanced loads
7. Small footprint
8. It does not contribute to short circuit current
9. Symmetric lead-lag capability
10. No moving parts, maintenance is easy
11. No problem of loss of synchronism in case of major disturbance

8. STATIC VAR COMPENSATOR (SVC)

SVC is a first generation of FACTS controllers. It consists of anti-parallel connected thyristor valves configuration with a reactor through which a current can be controlled making SVC a variable impedance device. Basically thyristor valve technology of SVC is advancement in HVDC technology. The major difference is that SVC is connected to a transmission system through step down transformer, so the thyristor valves of lower voltages are required for this. Often these thyristor valves are connected to the tertiary winding of a power transformer **[1].**
Initially SVC was used for the load compensation of the frequently changing load conditions found in steel mills, arc furnaces etc. Later the objective of the device is to provide dynamic power factor improvement and voltage control. These applications of the SVC were started in the late seventies **[3].**

Major objectives of the SVC are:

1. To improve power transfer over long lines
2. To improve system stability by providing voltage control
3. To dampen the low frequency oscillations due to power swings
4. To damp frequency oscillations due to torsion modes.
5. To provide dynamic voltage control

SVC is based on simple inductive and capacitive elements. The control function is comprised of simple power electronics devices. It has no inertia i.e. it is not based on any rotating machine like synchronous condensers **[3].**

8.1 CONFIGURATION OF SVC

SVC is comprised of following major components:

- Coupling Transformer
- Thyristor Valves
- Reactors
- Capacitors

SVC provides the voltage regulation at the point of its connection by injecting or absorbing the reactive power form the power system. When the power system voltage is low, SVC will generate reactive power and its mode will be capacitive, conversely when system voltage is high, SVC will absorb reactive power from the system and its mode will be inductive. This control of reactive power is performed by switched capacitors and controlled reactors **[3]**.

The two main configurations of the SVC are:

1. Fixed Capacitor- Thyristor controlled reactor (FC-TCR)
2. Thyristor switched capacitor – Thyristor controlled reactor (TSC-TSC)

Thyristor controlled reactor (TCR) with the help of a reactor is used to control the fundamental-frequency current component by delaying the closing of the thyristor switch w.r.t. natural zero passages of the current. The circuit of a FC-TCR is as shown in fig. 10 below: **[3].**

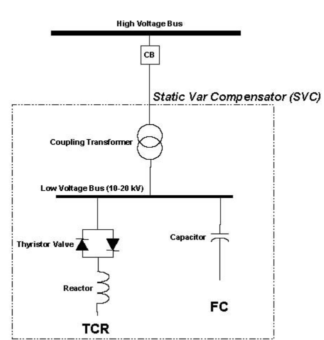


Figure 10: Configuration of FC-TCR [3].

TCR is made of a fixed reactor and an anti-parallel thyristor valve as shown in the fig. 11 of single phase TCR below.

By methods of firing delay angle control, the current through the reactor can be controlled from maximum to zero. [3].

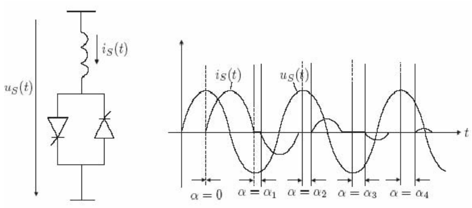


Figure 11. Single-Phase TCR [2].

The duration of intervals related to the current conduction can be controlled by delaying the closure of the thyristor valve with respect to the peak of the applied voltage in each half cycle.

As shown in the fig. above, for $\alpha = 0^{\circ}$ the amplitude of the voltage is at its maximum and for $\alpha = 90^{\circ}$ the amplitude is zero i.e. no current is flowing during that half cycle. Thus current through the reactor is achieved by firing the thyristor at desired conduction angle [2].

The basic concept of TSC is used to divide a capacitor bank into small capacitor steps of adequate size and switching on-off of these steps individually using anti-parallel switching thyristors configuration.

Unlike TCR, TSC can be switched out at zero passage of the current. This circuit of TSC-TCR is shown in the fig. 12 below:

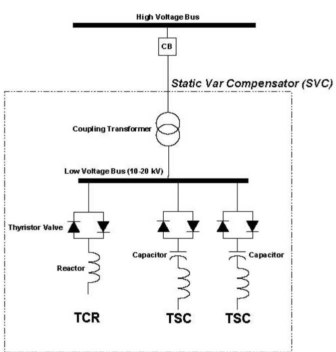


Figure-12 Configuration of TSC-TCR [3].

As shown in fig. 13 below, when the current is passing through zero, capacitor becomes fully charged and reached its peak value. In the second mode, the disconnected charged capacitor ideally stays at peak value. Now the voltage across the non-conducting thyristor varies in phase with the applied voltage.

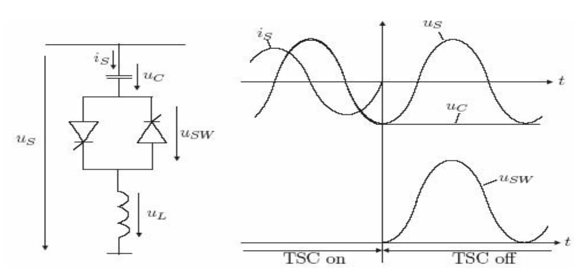


Figure 13. Thyristor Switched Capacitor [2].

At the time the thyristor is switched out, the voltage across the capacitor immediately discharged after disconnection. Now as the voltage across the conductor is equal to the AC voltage, the reconnection of the capacitor rakes places i.e. the instance when the voltage across the thyristor valve is zero [2].

The switching of the capacitor may introduce transient disturbances which could result in an instantaneous current in the capacitor. In order to minimize these transients capacitor switching must occur at some specific instants in each cycle. Therefore a current limiting reactor has been placed in the branch to minimize the current in the capacitor that would occur due to its switching. Hence TSC is a capacitive admittance device which is either connected to or disconnected from the AC system [2].

CHARACTERISTICS OF SVC

The modes of operation of SVC are:

1. Voltage regulation mode
2. VAR control mode

In voltage regulation mode, SVC has the following V-I characteristics: **[1].**

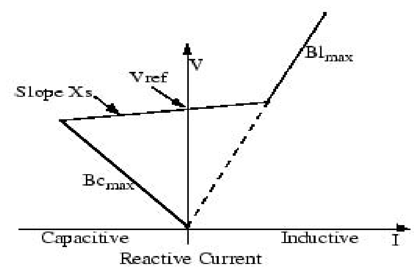


Figure-14. V-I Characteristics of SVC [1].

$-Bc_{max}$ and Bl_{max} indicate the maximum and minimum values of the susceptance required by the total reactive power of capacitor & reactor banks. Now as these susceptances are within the range as shown in the characteristics above, voltage will remain regulated at the reference voltage V_{ref}. The slope Xs can be adjusted within 1% to 4%. In voltage regulation mode, the V-I characteristics of the SVC can be defined with the following three equations: **[1].**

$V = V_{ref} + X_s.I$

$V = - I/Bc_{max}$

$V = I/Bl_{max}$

Where

V = System Voltage

I = Reactive current of the SVC

X_s = Slope reactance

V_{ref} = Reference voltage to the converter

Bc_{max} = Maximum capacitive susceptance with all TSCs in service

Bl_{max} = Maximum inductive susceptance with all TCRs in service

8.2 APPLICATIONS OF SVC

The major applications of the SVC are: **[1,2].**

1. Rapid voltage regulation
2. Control of temporary over-voltages on load rejection, faults or other transient disturbances
3. Compensation for flicker
4. To extend the stability limits by providing the voltage boost within a transmission system
5. To provide the dynamic voltage support at weak points in meshed transmission networks
6. To contribute to the reduction of harmonics distortion in a system
7. To damp low frequency oscillations at high loading conditions
8. To balance single phase loads
9. To permit greater flexibility in planning the supply of reactive power in power systems by the ability to relocate static compensators.
10. To extend the transmission distance while maintaining acceptable operating voltages at any load.

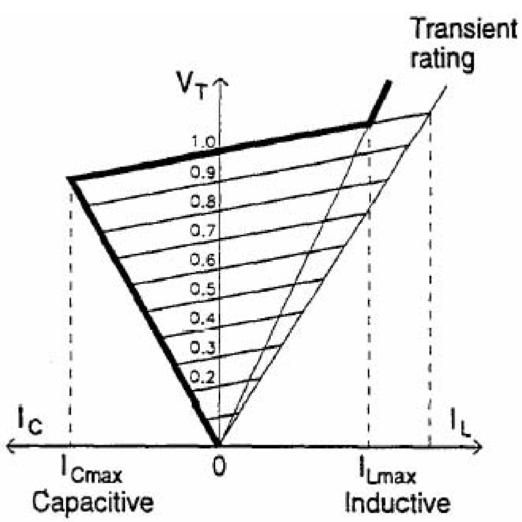
8.3 ADVANTAGES OF SVC

The main advantages of SVC are: **[1].**

1. Faster response under transient conditions
2. Cost effective solution
3. Effectively improve voltage control
4. No moving parts, hence requires less maintenance
5. No problems related to loss of synchronism
6. No contribution to short-circuit currents

8.4 COMPARISON BETWEEN SVC AND STATCOM

Both SVC and STATCOM are fast response shunt compensators, their comparison can be made with the help of V-I characteristics: **[1,2].**



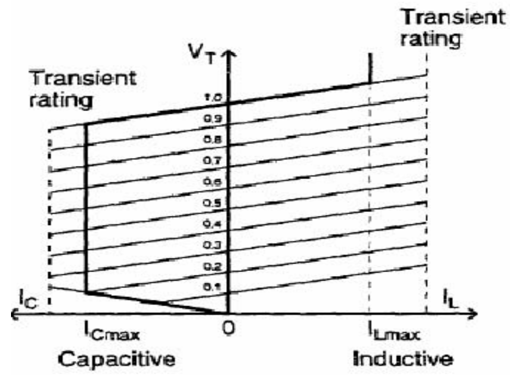


Figure 15. V-I Characteristics of SVC (left) & STATCOM (right) [2].

It is quite clear from the V-I characteristics that the STATCOM has more capacitive and inductive current range as compared to SVC and is capable of providing more output current than SVC. Moreover STATCOM can provide full capacitive output current at any system voltage, even down to zero, whereas SVC provides only moderate output current with the decreasing system voltage **[2]**.

Furthermore, it is obvious from the characteristics that the transient rating of the STATCOM is greater in capacitive & inductive regions whereas the transient rating of the SVC is dependent on the size of the capacitor **[2].**
In addition STATCOM provides the much faster response than SVC because STATCOM do not possesses any kind of delay in firing of thyristors and this is only because of a voltage-source converter **[2].**

9. SIMULATION AND ANALYSIS OF STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

9.1 VOLTAGE REGULATION OF 500/230 kV NETWORK WITH STATCOM

The power system in which a STATCOM is installed to control the voltage is a 500 kV /230 kV transmission systems, connected in a loop configuration, consists of five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants are located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 300 MW, 300 MVAR & 200 MW, 200 MVAR RL load connected at buses B2 & B3. The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). Tr2 is considered as bank of 3 x 400 MVA Transformers, but in here a contingency case has been taken in which 2 x 400 MVA transformers are in operation. The single line diagram of the network is as shown in fig. 16 below [5]:

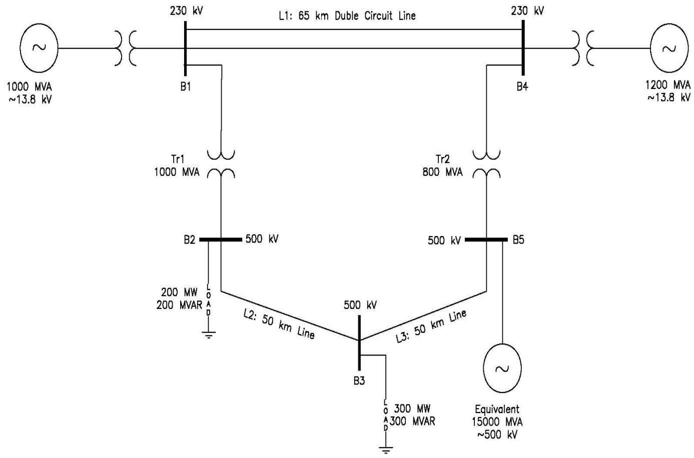


Figure 16. Power System under study [5].

10. Conclusion

The operation of power system today is getting more complex due to the involvement of lot of controls at different levels i.e. at generation, at transmission and at distribution end. Some of these operations have to be controlled manually by the operator and his rapid decisions are required in this regard. So the need of the hour is to develop an automated system so as to minimize the human eye errors by operators resulting into an unstable system. FACTS devices provide proven technical solutions and measure the changes in the system automatically and alter the way system are developed and control together with improvements in asset utilization, system flexibility and system performance.

Pakistan's EHV system is an essentially North-South radial line network, with the main load centres being situated largely at the two ends. Even as this may appear to be a basic view of the transmission system, it helps in certain considerations, given that the Northern areas are seasonally generation intensive and the Southern end has large fossil fuel fired and nuclear generation. This indicates the necessity of an operational ability to exchange power to needs at both ends of the country, not simply to satisfy the overload demands, but also to promote stability across subsystem boundaries such as that of WAPDA grid and KESC EHV network.

In order to promote overall increase in transmission capability and stability margin alongside oscillation damping to such network shunt compensation is a useful option near the two load ends for transient & dynamic stability improvement.

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Street Lighting and Fence Lighting in Power Stations in Saudi Arabia

By

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ABSTRACT

In Saudi Arabia in most of the cities the street lighting and fence lighting in powerhouses is fed by two phase wires (i.e. no neutral wire is utilized). This queer aspect poses some special problems.

Normal methods which are used for ascertaining the line currents in the case of star connected 3-phase 4 wire systems (with balanced loads) cannot be used. Some special methods are used to find out line currents. These line currents are essentially required to calculate proper cable sizes.

There are various methods (e.g. Millman's theorem etc.) for the solution of unbalanced loads but another simple approach to the problem is followed in this paper and the requisite line currents are determined.

INTRODUCTION

In Saudi Arabia, the low voltage distribution voltages in different cities are not the same. For example in Makka distribution transformers are 3-phase, 11000/400 volts type having Dy11 connections. The secondary is having star-connected 3-phase 4 wire system and the phase to ground voltage is 230 volts while phase to phase voltage is 400 volts. Lights and small power loads are fed by 230 volts single phase circuit while three phase motors are fed by 3 phase 400 volts circuit. However, in Riyadh, Jeddah and Dammam etc, the phase to phase voltage is 220 volts while phase to ground voltage is 127 volts. The distribution system is star-connected 3-phase 4 wire type. For every house or office, two phases as well as a neutral is provided; for lighting and small power 127 volts single phase circuit comprising a phase wire and a neutral wire is provided while for air-conditioners and other heavy loads, two phases are utilized for feeding those.

Large Power Stations as well as Large High Voltage Substations have vast lands which also have asphalt roads. Invariably street lighting has to be provided along such roads. In most of the cases, it is fed by two phases only. Further due to security reasons, fence lighting which is also fed like street lighting, has to be essentially provided.

THE PROBLEM

As per Saudi Electricity Company (S.E.C) Abha's Technical Specifications all indoor lights as well as small power is to be fed by single phase 127 volts circuits; however, street lights as well as fence lights are to be fed by two phases.

S.E.C. requires that complete calculations should be submitted by the Contractor to ascertain the adequacy of the feeding cables. However in the case of street lighting and fence lighting, feeding by two phases make the problem somewhat complex.

BALANCED AND UNBALANCED LOADS

Suppose we have a star-connected 3-phase 4 wire polyphase a.c. system and the number of lamps (each of say 250 watts) on Red, Yellow and Blue phases are 5, 6 and 7 respectively. In such a case the loads, being unequal on the various phases, will be termed as unbalanced loads.

In our particular case, stated below as "A Case Study", since each load i.e. each street light lamp is fed by two phases, so the loads are delta connected unbalanced loads.

Unlike unbalanced star-connected load, the unbalanced delta connected load is independent of the nature of the load and is equal to line voltage. In fact the problem resolves itself into three independent single-phase circuits supplied with voltages which are 120 degrees apart in phase.

The different phase currents can be calculated in the usual manner (a calculation is attached for guidance) and the three line currents are obtained by taking the vector difference of phase currents in pairs.

A CASE STUDY

In K.S.A the Electricity Company is owned by Government and its name is Saudi Electricity Company (S.E.C).

S.E.C (South) had awarded a contract to a Saudi contracting company named Altoukhi Company Riyadh for the extension of Jezan Thermal Power Station. This work also involved installation of some street lighting as well as fence lighting and both had to be fed by two phases of a 3 phase, 4 wire 220 volts system. The Technical Specification stated that the minimum size of underground P.V.C insulated copper cable shall be 3 core x 25mm^2. Further an Earth Continuity Conductor abbreviated as E.C.C. (an insulated green coloured cable) of appropriate size (refer to Annexure – 2) shall also accompany the above said cable from the Lighting Distribution Panel upto the last street lighting pole. Contractor was required to submit complete calculations including computer print-outs regarding illumination design as well as cable sizing calculations.

In K.S.A there is a big private company named Saudi Lighting Company in Riyadh which manufactures various types of lamps and lighting fixtures. They have purchased a computer software from Germany which can produce computer print-out for indoor lighting as well as for street lighting.

As a first step the Contractor approached the above said Saudi Lighting company and gave them drawings showing plans of streets where street lights were required;

the latter

was also informed that the height of the street lighting poles shall be 8 meters and High Pressure Sodium Lamps of 80 watts shall be installed. Further as per Contract's Technical Specification the lux level shall be 100 Lux. On the basis of above cited data and the software, Saudi Lighting Company provided the computer printouts to the Contractor.

As a second step, the Contractor was required to provide proposed cable size calculations to S.E.C (South). In Figure - 1 is shown the layout plan regarding lighting poles and the Contractor had proposed that poles # 1 to 15 would be fed from circuit # 1 and poles # 16 to 31 would be fed from circuit # 2; both the circuits would be 2 phase (and a green coloured E.C.C) circuits. The above arrangement had made the calculation quite simple. However, S.E.C (South) did not approve the proposal and they demanded that instead of laying 2 phase cable, a 3 phase cable (and a ground insulated wire) should be installed.

It is added here that invariably each street lighting pole has a lockable box contained within the pole at a height of about 50 to 60 cm above the ground level. The box has a door and a terminal box (for incoming and outgoing cables) as well as a fuse for the protection of 80 watts lamp. Between the terminal box and the above said lamp which is mounted on the top of the pole, three (3) insulated copper wires (one for phase, the second for neutral and the third as E.C.C) of 2.5 mm^2 cross-section are installed.

METHODOLOGY

(1) Refer to Figure – 1 and in accordance with the method of moments indicated in Reference - 1, ascertain the equivalent distance "L" for the longer of the two circuits i.e. circuit # 1.

(2) A perusal of Figure – 1 indicates that the maximum load is being fed by "R" and "Y" phases.

(3) The loads are in the form of unbalanced delta connected loads. As explained in Annexure – 1, by some simple formulas the line currents are determined.

(4) As per N.E.C (U.S.A), voltage drop allowed is 3%. This means permissible voltage drop between the Lighting Panel and the last lamp is 220 x 3/100 = 6.6 volts.

(5) Refer to Table - 48 wherein ampacity and milli-volts per ampere per meter for various cable sizes are indicated. On the basis of length "L" and load in Amps, ascertain the voltage drop for various sizes and select the most appropriate 3 phase 3 wire cable size. It should be borne in mind that the simple calculation procedure stated in this paper should not be applied if the cable size is 35 mm^2 or more. In that case another method which takes into account resistance and reactance of the cable (which is not explained here) is used.

(6) Confirm that the cable which satisfy "voltage drop condition" also satisfy ampacity considerations.

(7) Further check whether the selected cable is adequate to withstand the three phase symmetrical short circuit current.

(8) The finally selected cable size will be the one which meets all the above said three considerations.

(9) In addition to the 3-core cable, a separate E.C.C of appropriate size shall also be laid for each circuit. Refer to Annexure – 3 in this regard. It is also possible to use a 4-core cable and in that case one of the cores is used as E.C.C.

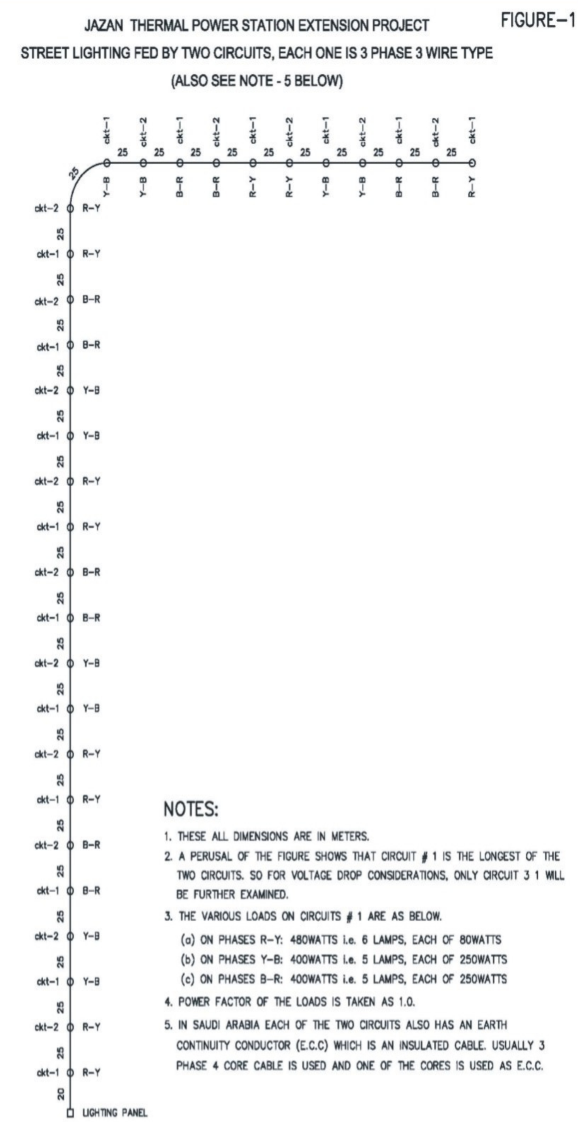
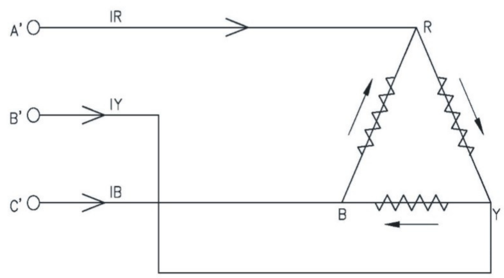


FIGURE-2

LINE CURRENTS IN DELTA CONNECTED LOADS



CONCLUSION

In Saudi Arabia, in most of the cities, street lighting and fence lighting is fed by two phases. The loads are delta connected loads.

A complete case study showing detailed calculations has been included.

The calculations have shown that to ascertain proper size of the feeding cable, the following three conditions should be satisfied.

(1) Ampacity Condition

(2) Voltage Drop Condition

(3) Short Circuit Condition

Further an E.C.C of appropriate size as indicated in Annexure – 3 shall be laid for each circuit and its perusal shows that 10 mm^2 is the one which should be used. Since 4-core 25 mm^2 cable with reduced neutral (i.e. 16 mm^2) is also available, therefore, it is recommended to use the same; in this case a separate E.C.C will not be required.

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(2) National Electrical Code (Year 2008 Edition) U.S.A, Published by National Fire Protection Association, U.S.A.

Table – 48: Voltage Drop

Approximate voltage drop or 0.6/1 kV cables having stranded copper conductors solid.

Nominal Area of Conductor	Approximate Voltage Drop per Ampere per Meter	
	Copper Conductor	
	single-core	Multi-core
mm^2	mV	mV
1.5	-	25
2.5	-	15
4	-	9.6
6	-	6.4
10	-	3.8
16	-	2.4
25	-	1.5
35	-	1.1

Note: Tables No. 48, 50, 51, 53 and 54 are taken from a Saudi Cable Company's catalog and the name of the company is CABLECO.

Table 50: Current Rating for Cables with Copper Conductors

National Conductor Cross-Section	Maximum Conductor Temperature 70° C					
	Single-core Cable		Twin Cable		3 and 4 Core	
	Earth 20° C	Air 20° C	Earth 20° C	Air 20° C	Earth 20° C	Air 20° C
mm^2	Load in A					
Copper Conductor						
1.5	37	26	30	21	27	18
2.5	50	35	41	29	36	25
4	65	46	53	38	46	34
6	83	58	66	48	58	44
10	110	80	88	66	77	60
16	145	105	115	90	100	80
25	190	140	150	120	130	105
35	235	175	180	150	155	130

Table 51: Conversion Factors for Current ratings, Depending Earth Temperature for 70° Maximum Conductors Temperature

Ambient Temperature °C	15	20	25	30	35	40	50	55
Conversion Factor	1.05	1	0.95	0.89	0.84	0.77	0.63	0.55

Table 53: Conversion Factors for Current Ratings Depending on Earth Resistivity

National Conductor Cross Section mm²			Specific Earth Resistivity GE C Cm/W						
			70	100	120	150	200	250	300
3-and 4 core Cable	up to	25	1.11	1	0.94	0.87	0.78	0.72	0.67
	35 upto	95	1.13	1	0.93	0.86	0.76	0.70	0.64
	120 upto	240	1.14	1	0.93	0.85	0.76	0.69	0.63
	300 upto	500	1.15	1	0.92	0.85	0.76	0.68	0.63

Table – 54

Adequacy of P.V.C Cable (having copper conductors) against short circuit currents

Size of Cable	Short Circuit Current which it can withstand	Remarks
4 core x 10 mm^2	0.94 kA	Duration of short Circuit Current is 1 second
4 core x 16 mm^2	1.504 kA	Duration of short Circuit Current is 1 second
4 core x 25 mm^2 (or 3 core x 25 + G 16 mm^2)	2.35 kA	Duration of short Circuit Current is 1 second

Formulae used is $I_{SC} = \dfrac{0.094\ A}{\sqrt{t}}$

I_{SC} = Short Circuit Current in kA (kilo-amps.)

A = Conductor area in sq mm

t = Short Circuit time in second

Table – 54

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I_{SC} = Short Circuit Current in kA (kilo-amps.)

A = Conductor area in sq mm

t = Short Circuit time in second

ANNEXURE – 1

CALCULATION REGARDING LINE CURRENTS FOR UNBALANCED DELTA CONNECTED LOADS

A 3-phase system usually has RYB phase sequence system. Here the voltage of phase Y lags behind phase R by 120 degrees and that of phase B lags behind phase Y by 120 degrees. Hence in the vector form the voltages cab be stated as

$E_{RY} = E\ \angle 0^0 = 220\ \angle 0^0$

$E_{YB} = E\ \angle -120^0 = 220\ \angle -120^0$

$E_{BR} = E\ \angle -240^0 = 220\ \angle -240^0$

– Six (6) lamps each of 80 watts are fed by phases R-Y, while five (5) lamps are fed by phases Y-B. Similarly phases B-R feed 5 lamps.

Since P = V I cos ϕ = V^2/Z cos ϕ. Assume power factor (p-f) is 1.

then P = 480 =

$$\frac{(220)^2}{Z} \; or \; Z_{RY} = \frac{(220)^2}{480} = 100.83 \; ohms$$

Similarly $Z_{YB} = \dfrac{(220)^2}{400} = 121 \; ohms$

and $Z_{BR} = \dfrac{(220)^2}{1250} = 121 \; ohms$

Since by Ohm's law, I = E/Z

So $I_{RY} = \dfrac{220}{100.83} = 2.18 \; Amp$ = (in magnitude only)

I_{YB} = 220/121 = 1.82 Amp (in magnitude)

I_{BR} = 220/121 = 1.82 Amp (in magnitude)

Taking V_{RY} as the reference vector, we get

I_{RY} = (2.18 + j 0)

I_{YB} = 1.82 [- 0.5 – j 0.866] = - 0.91 – j 1.58

I_{BR} = 1.82 [- 0.5 + j 0.866] = - 0.91 + j 1.58

Hence Line Currents (refer to Figure – 2) for delta connected loads are:

$I_R = I_{RY} + I_{RB} = I_{RY} – I_{BR}$ = (2.18 + j 0) – (-0.91 + j 1.58) = 3.47 Amp (in magnitude)

$I_Y = I_{YR} + I_{YB} = I_{YB} – I_{RY}$ = (- 0.91 - j 1.58) – (2.18 + j 0) = 3.47 Amp (in magnitude)

$I_B = I_{BR} + I_{BY} = I_{BR} – I_{YB}$ = (- 0.91 + j 1.58) – (-0.91 + j 1.58 = 3.16 Amp (in magnitude)

– From above, the maximum current is in I_R as well as in I_Y (refer to Figure – 2) and its value is 3.47 Amps.

– As per National Electrical Code (N.E.C) U.S.A, ampacity of the feeding cable must be rated at least 25% greater than the load current when the load functions continuously over long periods (3 hours or more). So the cable must be able to carry 3.47 x 1.25 = 4.34 Amps.

–

ANNEXURE – 2

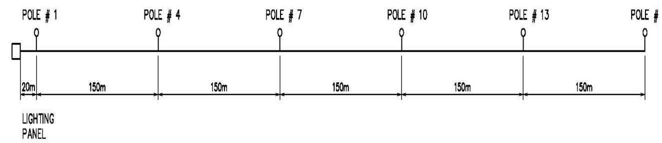
CALCULATIONS REGARDING CABLE SIZING

– Refer to Figure – 1. Two circuits are used to feed the various street lighting poles. Circuit # 1 being longer will be considered for the cable sizing.

– As stated in Reference (1), if two loads "W1" and "W2" are at distances L1 and L2 respectively from the lighting panel, then the above said two loads can be represented by a single load "W" at a distance of "L" from the lighting panel. In terms of Mathematics it can be said that WXL = W1 x L1 + W2 x L2. The same formulae can be used for the figure shown below.

– An examination of Figure – 1 shows that there are 6 lamps which are fed by Red and Yellow phases. Load of each lamp is 80 watts.

So equivalent Load "W" = 6 x 80 = 480 watts



So equivalent distance "L" from above formulae = 395 meters. (see Reference – 1 for details)

– Permissible voltage drop as per National Electrical Code (U.S.A) = 3 %

= 3/100x220= 6.6 volts ------- (i)

– Now we check the proposed cable for voltage drop, ampacity as well as short circuit fault. All these conditions must be satisfied.

– AMPACITY CONSIDERATIONS:

Since 3 x 25 mm^2 is the minimum size which is acceptable to S.E.C (South) as per Contract's Technical Specification (C.T.S), therefore we check the same cable in the earth as it is laid in a sand filled trench.

(a) In the Earth: Ampacity as per Table 50 for P.V.C cable = 130 Amps (at 20° C)

Earth's temperature given in C.T.S = 30° C

Temperature correction factor as per Table 51 = 0.89 -------- (ii)

– Correction Factor due to earth resistivity.

– Earth resistivity of the site as given in C.T.S = 200° C.Cm / W

– So correction factor from Table 53 = 0.78 --------- (iii)

– Corrected ampacity of the cable = 130 x 0.89 x 0.78 = 90.25 Amps. ----------- (iv)

– It is assumed that the two cables in the trench are not touching each other and these are separated by at least twice the outer diameter of the cable. Hence no reduction factor due to grouping is applicable.

– As given in Annexure – 1 the cable shall be adequate for a current = 4.34 Amps -------- (v)

– Since (iv) is more than (v), so ampacity condition is satisfied.

–

(b) Voltage Drop Consideration:

- From above, single equivalent load on the most heavily loaded phases is = 480 watts
- Equivalent distance L from above = 395
- Actual load current = 3.47 Amps
- From Table 48, millivolts per ampere per meter for 25 mm^2 cable = 1.5
- So voltage drop = 1.5/1000x3.47x395= 2.05 volts --------------------- (vi)
- Since voltage drop (2.05 volts) found in (vi) is less than (i), therefore, voltage drop condition is satisfied.

(c) Short Circuit Current Consideration

– The Lighting Panel is fed by a 3-phase, 100 kVA, 13.8 / 0.220 kV transformer. The value of short circuit current which is available on the secondary terminals of a 3 phase 100kVA transformer which has 5% impedance is:

$$\frac{100\,kVA}{\%\ impedance} \times 100 = 2000\ kVA$$

So 2000kVA=

$$\sqrt{3} \times I_F \times 220 \, or\, short\, circuit\, current\, I_F = \frac{2000}{\sqrt{3}\times 220} = 5.24\,kA$$

Now this is the fault current on the secondary terminals of the transformer. If this transformer is feeding some load through some L.V. cable, then at the load side of the cable the fault current will be less depending upon the length as well as the size of the cable. N.E.C (U.S.A) has given some formulas with the help of which it can be easily ascertained as to what will be the fault current on the load side of a cable of a particular size. Due to space limitation, this step is not explained in full detail.

– Fault level at the end of the cable at Pole # 1 is found to be 2kA. The attached Table - 54 shows that for a fault duration of 1 second, 25 mm^2 is adequate for the short circuit current. So the selected cable i.e. 3 core x 25mm^2 is adequate. It was stated in the C.T.S. that the said cable shall withstand a fault duration of 1 second. In view of E.C.C, a four core cable with reduced neutral (i.e. 3 core x 25 mm^2 + Ground 16 mm^2) can be used.

ANNEXURE – 3

NEC 2008, TABLE No 250.66

SIZING GROUNDING ELECTRODE CONDUCTORS FOR A.C. SYSTEM

Size of Largest Service Entrance Conductor (or Equivalent for parallel Conductors) AWG	Size of Copper grounding Electrode Conductor, AWG	Recommended Grounding Electrode Conductor in mm^2 size
2 AWG or smaller	8 AWG	Use 10 mm^2 insulated conductor
1 AWG or 1 / 0	6 AWG	Use 16 mm^2 insulated conductor
2 / 0 or 3 / 0	4 AWG	Use 25 mm^2 insulated conductor

NOTE 1:- It is just a part of the Table. For complete information refer to N.E.C (USA) 2008, Table No. 250.66.

NOTE 2:- AWG sizes and their equivalent mm^2 sizes are as given below:

AWG Sizes	Equivalent mm^2 Size	Remarks
2	33.62	Use 35 mm^2 insulated conductor or Cable
4	21.15	Use 25 mm^2 insulated conductor or Cable
6	13.30	Use 16 mm^2 insulated conductor or Cable
8	8.37	Use 10 mm^2 insulated conductor or Cable

Solar Power To The Rescue!

Engr Tahir Basharat Cheema

President

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It was only a few days ago that the chairperson of the Pakistan Engineering Council (PEC) propagated solar power as the tool to overcome the ongoing energy crises. Though the PEC, regulator of the badly managed engineering profession in Pakistan, should be more concerned with other imperatives more in line with its core responsibilities than propagating any specific form of generation, still the utterances were most timely. It all attains even more importance when seen in the context of the current level of load shedding and the governmental worries to contain the damage. It was also in news that UK has decided as a national goal to assure 25% of its total generation needs from wind-power by 2020. A stupendous goal, when their total requirement then would be 66,000 MW and while the actual installed capacity of the wind power may cross the 26,000 MW mark, considering that typical load factor of such generation remains low and around 24% for the UK (even its extremely windy North Sea area to support such a cause). Consequently, it would be appropriate to implement such a scheme in Pakistan too, which would correct the present spoiled generation, fuel and customer mix of the country. It would also stem the need for another increase in the power tariff by 20%, when 64% average increase has already taken place along-with the monthly fuel price adjustments (adding to the bills regularly). Increased energy security from decreased fuel imports is another reason in support of resort to renewable energy (RE). We must also learn from other examples. Consider Australia where presently 92% of their power generation is fueled by cheap indigenous coal with no pressure to raise tariff. They have still implemented a very ambitious solar energy program and the skyline is covered with the shiny black of PV panels. Similar is the situation with the Germany, where at the moment 18,000 MW is being generated through PV based solar power systems. Many other countries like Spain are also fastly catching up. Malaysia, Singapore, India and China are other players in the run.

From the above, we see that amongst the many steps that need to be taken primarily to improve upon the present management of the sector and for transferring the actual ownership of the same to the Ministry of Water & Power alone, introduction of solar power into the menu of existing generation mix is of prime importance. And the right way is to engage every Pakistani into the scheme of things. The public and the private sectors engaged in generation may set-up solar power stations of both the PV based and the concentrated type, while the general people would install micro systems for their residences, commercial set-ups and industries. For this NEPRA, under guide-lines of the GoP (this provision still exists to the chagrin of the MLDAs), may allow feed-in tariffs (FITs). Additionally, the GoP would have to formulate/draft the needed Electricity Feed Act which would legally regulate the feed-in of electricity generated from renewable sources to the national grid – primarily solar power (some wind power too can be attracted in the coastal and hilly areas). This act will require the utility companies (DISCOs) to purchase electricity generated from the consumer solar power systems etc at set rates. Depending upon as to what national goals are set, we can have either gross or net feed-in tariffs–however, the net feed-in tariff also known as export metering is recommended. Here, the PV system owners get paid for the surplus energy produced. In other words, this plan would offer payment to the system owners for the electricity they feed back into the grid over and above what is used at their own homes and at a premium. These payments can be calculated and then made on the monthly basis or on the yearly basis. And the goal setting has to be stringent Pakistan may thus set a target of meeting 10% of its needs through solar power systems by 2020.

How do we do it in Pakistan? A little foray into statistics reveals that a total of 20.5 million customers presently stand connected to the PEPCO system, while another 3.0 million or so are on the KESC rolls. Out of these, 21 million fall under the category of general customers (which includes both domestic and commercial customers). Amongst these, a hefty 8 million can be termed as affluent customers with monthly average usage of beyond 300 units. On the other hand, the installed load of these customers should actually be more than 5 KW. This translates into the requirement of a 1KW solar power systems for this category which can cater to at least 10-20% of their demands. In financial terms, a 1 KW solar PV based system costs Rs.500,000/- or half a million and while keeping the prevalent power tariff of the utilities in view the payback period for it has been calculated to be anything between 3-10 years. Now the question arises so to why would an existing customer take the trouble and expense to go for a solar power system, when he is already using UPSs and generators. The answer lies in the fact that UPSs in Pakistan are extremely inefficient, (between 19% to 45% efficiency at the most), delivering highly impure power, sending surges (the cause for burnt fans and damaged electronic equipment) and lastly eating–up batteries. The charging of the standby systems adds hefty amounts to the monthly utility bills. The generators, are even more inefficient (efficiencies end at 18% to the max) and most expensive to maintain. The noise and smoke pollution which accompanies such equipments further tips the ante against generators. PV based solar power systems, on the other hand, are nearly maintenance free, environment friendly and need no fuel at all.

How do we arrange for the cost of installation of the Solar Power system, which is needed to be expended up-front. Here, the GoP will have to arrange for the banking sector to come-up with a special package akin to what is available in our neighboring India, where finance to install solar kits are available at 4% markup only. Additionally, the feed-in tariffs would be 150% of the utility tariff–thus allowing the customer to gain by 50% on each unit generated by his system, which could then be plowed back to re-pay the loans sought for the original installation. The utility concerned would keep an account of this import and then pay such customers through adjustment in their utility bills on the monthly, the three, the six monthly or the yearly basis. The padded-up of FIT would be underwritten by the GoP. However, the amounts thus expended would be much less than the tariff differential subsidy amounts being paid presently.

So as to ensure that the prospective power customers also get on the band wagon, a special legislation would have to be enacted in support of the already enacted Building Code, whereby all new residential units of 10 marlas and above in the bigger of the urban cities would be under an obligation to arrange for 10-20 % of their needs from solar power and other RE systems. Otherwise, they would be deprived from any access to the power and gas utilities. Thereafter, the facility of feed-in tariff would be available to them and so would be the facility of low mark-up loans. Additionally, all new commercial units / plazas would be under a similar obligation. And in order to facilitate conversion to solar systems and to achieve the minimum goal of production of 5000 MW of such power by 2020, tax rebates are also recommended to be allowed by the GoP. This would further improve upon the chances of a quick addition to the tally of solar power. And in order to institutionalize the plan, the ownership for implementation would rest with the AEDB, while organizations like the EDB, NPO, PSQCA, PCST, PEPCO and such others would assist and ensure indigenization, reduction in costs and further improvements in the systems. Mid-course changes on the basis of technological advancements etc would also be made or recommended by these organizations on the as and when needed basis. On the other hand, governmental support is going to be of great import as otherwise sustainability of the plan could never be assured. Moreover, NEPRA as the regulator would have to act at the watchdog–specially, when solar power (and other means of RE) will lead to affordability of power for the people, besides in less dependence on imported / polluting fuels etc.

What are the expected gains of this scheme of things–very simple, the oil bill would reduce in an exponential manner starting from US$ 200 million in 2012-13 to a full US$ 10 billion or so by 2020. Additionally, the yearly burden of power utility bills (on today's cost) for the already beleaguered power customers would reduce by 10% to the maximum – which is a game changer. This would also allow the utility business to change and come out of the straight jacket it is presently in. In the long run, the association between utilities and the customers would be that of partners, thus doing away with the adversarial role evident at present.

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Quotation

- Whose loves believes the impossible.
  Elizbeth Barrett Browning
- Men always want to be a woman's first love – women like to be man's last romance.
  Oscar Wilde
- Love is like war: easy to begin and hard to stop,
  H.L. Mencken
- Love and cough can not be hid
  George Herbert
- All's fair in love and war
  Francis Edard Smedley
- Passions are vices or virtues in their highest powers.
  Johan Wolfang van Goethe
- The greatest pleasure in life is doing what people say you can not do.
  Walter Bagehot
- There are three kinds of lies: damned lies, and statistics.
  Bangamin Disraeli
- Truth exists, only falsehood has to be invented
  George Braque
- Facts are to the mind what food is to the body
  Edmund Burke
- A fool without fear is sometimes wiser than an angel with fear.
  Nancy Astor
- Fools rush in where angels fear to tread.
  Alexander Pope
- Fine clothes many disguise, but foolish words will disclose a fool
  Aesop
- Everyman has his follies – and often they are the most interesting things he has got.
  John Heinrich Voss (attrib.)

Can Power Tariff Go Down?

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The people of Pakistan, especially the power customers, have great grouse against what is commonly referred to as WAPDA. Although, WAPDA's power wing has since long been de-bundled under a reform programme and converted into GENCOs, the NTDC and nine DISCOs, the people still refer to the power issues as pertaining to WAPDA alone. The main complaint against the DISCOs is the extremely high tariff which has seen an average 100% rise during the last three years. That this rise has been up to 200% for some categories and around 50-70% only for some further complicates the scenario. The power sector managers, on the other hand, talk of certain factors beyond their sway as being responsible for the steep rise in prices–foremost being the inordinate jump in oil prices from a low of US $37 to US $ 100 at present. They further propagate that the burden of oil prices has manifested in a debilitating manner because the earlier requirement of 780 mmcfd of gas has since been curtailed to as low as about 250 mmcfd for the public sector GENCOs alone. It is further informed that the firm allocation of 70 mmcfd for KAPCO against the full need of 200 mmcfd (once WAPDA's flagship venture and now privatized) too has been cancelled since the last three years through the non-extension of the binding gas supply agreement with SNGPL.

The money managers of the power sector further inform us that full gas supplies to the sector can easily bring the power tariff down by a hefty 30%, thus doing away with the imposition of the current level of the monthly fuel price adjustment. Incidentally, this price adjustment is the present bone of contention between the DISCOs and the customers– so much so that nearly all the high courts are privy to litigation in this regard. Although, the courts have issued restraining orders, but the final decisions are bound to allow the legally determined adjustments (by NEPRA) to be recovered from the customers. Agreeing to the above thesis, the requirement boils down to one specific issue viz. that somehow the earlier withdrawn gas has to be returned to the power sector at least for the coming 2-3 years and during which other solutions for the conversion of existing public sector power plants to cheaper fuels could be undertaken. This seems to be an uphill task specially when the country is facing a 1 bcf shortage of gas at present. Unfortunately, most of the professionals also consider any extra gas supplies to the power sector as a most unlikely preposition. However, the facts belie this thrust of opinion.

Consider. OGRA for gas (UFG) to be in the range of 13% or so for both the SNGPL and the SSGC systems. Imagine the savings if this figure could be brought down even by 1-3% in the coming 3 months, specially when huge amounts are available for this activity under World Bank/Asian Development Bank loans and USAID grants. It is further seen that 3.5 million gas fired water geysers are operating in the country and guzzling a staggering 600 mmcfd of gas. Simple installation of conical bafflers in the fire tubes of these geysers can save up to 30% of the fuel intake and full conversion to solar heater systems can subsequently wean the geysers away from gas use. It is such a viable idea that the gas companies and the DISCOs can jointly underwrite the provision of this gadget. Thirdly, it is in full knowledge of every one and which has been debated at all forums of the country that there is wide spread theft at the CNG stations across the country. The various banners strewn and displayed at these stations highlighting huge discounts attest to this conclusion, which is further bolstered when seen along with the high level of UFG in both the gas utility. The situation attains even more serious proportions when we see that CNG usage is on the rise with 58% increase in such usage in the south alone. Here, it is recommended that strict vigilance be undertaken by the gas companies and the defaulters and those indulging in illegal abstraction of gas be pinpointed for permanent removal from the pipelines. Additionally, it is seen that all the CNG stations are fed through the low pressure system, while the right way is to use high pressure pipelines for filling-up the CNG stations. This irrational way of dispensing gas is responsible for a loss of billions. Case in point would be the only 19 CNG dispensing points in the Dehli ICT (Indian Capital Territory) against more than 350 such facilities in Lahore. Consequently, but in sustained manner, the existing system has to be upgraded. The quick and hefty gains out of this exercise can easily be passed on to the power sector. It is also of merit to state that the human resource and other facilities of the power sector (DISCOs) can be used to supplement the efforts of the gas utilities. More so, when 2000 or so complaints and customer service centers of the DISCOs are already operating in the jurisdictional areas of the SNGPL and SSGC. Incidentally, such an offer from PEPCO was spurned by the SNGPL in early 2010. According to rough estimates, 183 mmcfd of gas can be saved through these measures alone**.**

Additionally, it is seen that most of the CNG suppliers at the busy intersections of urban areas are utilizing gas much more than their sanctions. A quick survey (easy when only a few sites have to be studied) can list the defaulters, who then can be corralled to stay within the limits. This according to experts can easily reduce the present usage by up to 10% .

Looking at the various sectors being fed by the gas companies, another group stands out menacingly as a predator. These are the captive power plants (CPPs) originally fed along with the CNG Pumps by both the SSGC and the SNGPL out of the cuts of GENCOs and the KAPCO (only one from the IPPs) made during the period 2000 to 2008. Here, it is seen that the usage has no reliance to the relevant clauses of the Gas Management and Allocation Policy of 2005, which specifically requires optimum and efficient use of such allocations through co-generation and combined cycle power plants. All what is needed now is the implementation of rules and the policy in vogue. This would arrange for the disconnection of a large number of the defaulters and surely immense savings–which could be passed on to the troubled power sector.

Experts from amongst the SNGPL and SSGC cadres further inform us that savings can also be made through ensuring use and sale of standards burner tips (12.0 million) in the country. According to these experts, a saving of up to 100 mmcfd of gas can be arranged in an operation spread over 5 years. This converts into a first year saving of 20 mmcfd on the average and double for the next year and so on, which is no mean achievement.

However, for this step the Regulator viz OGRA, Ministry of P&NR, the gas companies, ENERCON (correctly placed under the Ministry of W&P now after the wilderness of the last decade or so), PCSIR, PSQCA, etc. would all have to work in tandem.

At this point we would also talk about the requirement to stop giving any further gas connections or extension of pipelines. In fact, a downsizing plan has to be implemented whereby the system facing low pressure could be reduced under a set time schedule to maintain the technical parameters of a standard system. The right answer thus is the arrangement for providing LPG to the new domestic consumers through delivery and vending systems to be maintained by the SNGPL and SSGC companies. The private sector already in this business may carry on with their business in competition to the public sector. The necessity for this step can be gauged from the fact that 67,000 Kms of transmission / distribution lines in 2008 have now reached the unmanageable figure of about 90,000 KMs for the SNGPL alone. This step will contribute at least 100–200 mmcfd during various months of the year. More so, when seen in the context of the 106% upsurge in 2010 consumption in comparison to that of year 2000. Besides, this step would results in frugal use, conservation, reduction in UFG and rise in productivity of the nation through gainful use of the saved gas.

How do we take up this programme and also assure success?. An inter–company committee will have to be setup while being co-chaired by the additional secretaries of the Ministries of Water & Power and Petroleum & Natural Resources. This committee with members from GENCOs, CPPA, SNGPL and SSGC (DG Gas of the Ministry of P&NR can also co-opted) will be tasked to achieve the above listed savings in the least possible time and then duly monitored by the federal secretaries concerned. It is considered that true implementation of the various steps would result in the saving of up- to 250 mmcfd of gas and it's provision to the power sector will result in a reduction in power tariff by at least 10-15% in 6-12 months of operation. This scheme needs full commitment and seriousness, otherwise the gains would not be of the envisaged volumes. However, it would set the ball rolling for the attainment of energy efficiency in the Country.

Quotation

- It is better to keep one's mouth shut and be thought a fool than to open it and resolve all doubts..
  Abraham Lincoln
- Genius is the ability to put into effect what is in your mind.
  F. Scott Fitzgerald
- Genius is more often found in a cracked pot than in a whole one,
  E.B. White
- …..the man of genius… doest not steal, he conquers
  Alexander Dumans
- Patience is a necessary ingredient of genius.
  Benjamin Disraeli
- Genius does what ity must, and talen does what it can.
  Edward Bulwer - Lytton
- One machine can do the work of fifty ordinary men. No machine can do the work of one extraordinary man.
  Elbert Hubbard
- Genius is one percent inspiration and ninety nine percent perspiration.
  Thomas Alva Edison
- Wit lives in the present, but genius survives the future.
  Marqueite, Countess of Blessington
- What is the rarest quality to be met with among people of education
  Willian Hazlitt
- Humour is a painful thing told playfully.
  Charles W. Jarvis
- …..brevity is the soul of wit.
  William Shakeseare
- No dignity, no learning, no force of character, can make any stand against good wit
  Ralph Waldo Emerson
- Angles can fly because they take themselves lightly.
  G.K. Chesterton

Electronic Based Visual aid for Blinds (e-VAB)

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Abstract:

This paper presents the research and design methodology of an Electronic based Visual Aid for Blinds (e-VAB) using a Real Time Video Camera, a Bluetooth transmitter and receiver to communicate with an implanted Microchip inside the brain, which will in turn send the electrical impulses to the Visual Cortex. An eye is the blessing of almighty ALLAH, without which we cannot visualize the beauty of the world. There are a lot of people which are either blind by birth or have lost their eyes/sight accidentally or due to any disease. They encounter severe difficulties in survival and performing their daily life tasks. Therefore, the need for such aid arise for blind people so as to provide them a new and dramatic way of seeing and differentiating the objects.

Keywords—e-VAB: Electronic based Visual Aid for Blinds;Visual Cortex:Part of the brain's cerebral cortex responsible for processing visual information; Microchip: an integrated circuit device; Bluetooth: wireless technology standard.

I. Introduction

Blindness is such an increasing issue due to so many factors like different types of diseases, sudden accidents, environmental bad conditions, poisonous drugs and pesticides and so many others. Some types of blindness can be treated easily while some become permanent and cannot be cured. So for recovering such types of blinds, the scientists are working and making new researches to overcome these types of problems.Even when vision has failed, the mind's eye can see, given just the right voltage to just the right place in the brain [1]. So, keeping this phrase in mind, we motivated to go through a detailed research of eye, visual cortex and methodologies for a visual aid. Without sight the world is dark and gloomy, its colors are lost and life is meaningless. The blind people come across immense difficulties in performing their very basic daily lifeworks. Therefore, the"e-VAB"is proposed for the people who are either blind by birth or having a damaged/blocked optic nerve or have lost their eyes. The "e-VAB" will provide the seeing environment for all types of blinds which are having at least their visual cortex. This aid is the new advancement in the field of Electronic and Biomedical Engineering which will serve as an artificial eye for blinds.

II. Biological Background

Main parts of the visual system are eyes, Visual pathway and Visual Cortex. Every human being has a pair of eyes. The reflected light falls on the eyes, passing from the pupil of the eye reaches to the retina. The retina consists of special types of cells called Rods and Cones. The Cones work at the day time and their work is to differentiate between colors while Rods work at night time and help in seeing objects in dim light. The main logic of the propagation of the visual signals is to convert light energy into electric impulses. The optic nerve has the optic chiasma where the crossing of the visual signals occurs. The sight from the temporal side goes straight while from the nasal side comes across the optic chiasma. After chiasma, the visual signal goes to the primary visual area (V1) of the visual cortex.

III. Design Methodology

The focus of our research was to give a design procedure for a low cost and valuable visual aid which may enable seeing ability of blind people. This design technique may be divided into four steps as shown in the Figure 1:

Real Time Video Acquisition

Manipulation of the video parameters

Bluetooth Communication between outside world and visual cortex

Visual signal conversion into electrical impulse using Microchip

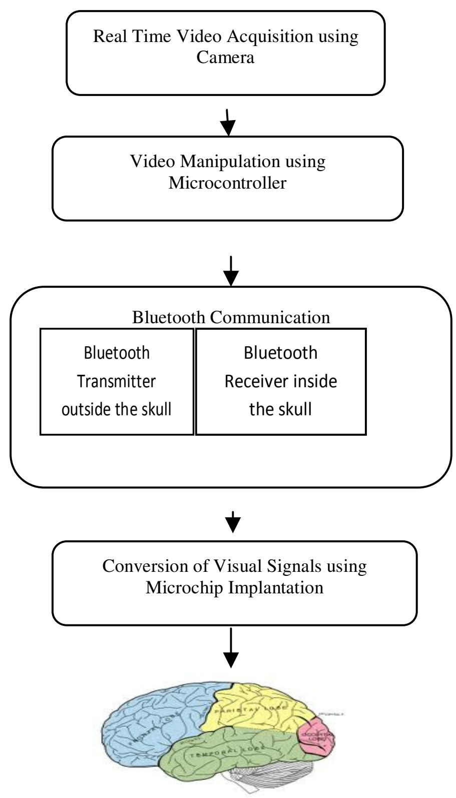

Figure1. Block Diagram for E-VAB

IV. Real Time Video Acquisition

The RTV (Real Time Video) Camera is used to process the real time video for transmitting visual data to the Microcontroller. The RTV Camera can easily be fixed in any type of ordinary glasses. The host (blind person) can easily put on that glasses and therefore easily portable. The camera consists of a focusing lens and its microprocessor. The camera is mounted in the glasses and it has an ON/OFF button for the user to make it ON or OFF according to his/her aspiration.

V. Video Manipulation

Video manipulation is done using a specially programmed Microcontroller, which will make the Visual data compatible to the Visual Cortex by inverting video and changing the voltage levels, intensity, wavelength and frequency required for the Visual Cortex. Video inversion is required because the images which pass from the natural eyes invert due to the presence of the convex lens present in the eyes. Therefore, before sending any images to the brain, they should be inverted as brain will again invert them and they will adapt their original form (erect from).

VI. Bluetooth Communication

The Bluetooth transmitter is mounted just behind the occipital lobe at the neck close to the visual cortex to transmit manipulated visual data inside the skull. It has no side effects on the brain or any other sensitive parts of the body like blood capillaries and neurons. The Bluetooth receiver, which is attached to the micro-chip which is already implanted inside the skull on the optic nerve or directly in the visual cortex, receives the information (visual data) from outside the skull.

VII. Microchip Implantation

The micro-chip [2], which will be implanted inside the brain, will be made up of biomaterial which has no hazardous or side effects on the nearby neurons of the brain and it will not require any fatal surgery, only a microchip once implanted for the rest of life. It depends on the condition that either subject's optic nerve is agreed to transmit/pass information to the visual cortex or there is some sort of blockage/damage. If the optic nerve is in a healthy condition then we can implant the micro-chip on the optic nerve and if there is any blockage then we can implant the micro-chip directly at the visual cortex. The visual signals should be provided to both the hemispheres of the visual cortex of the brain so as to give a complete view of the image to the host.The micro-chip converts visual signals, which have been received by Bluetooth Receiver, into small electrical impulses. There is always a threshold for activating any neuron in the body so the threshold for the optic nerve to create action potential is approximately from -60mv to -70mv.These small electrical impulses can cause action potential in the neurons and thus result as the transfer of visual signals from micro-chip to the visual cortex.

VIII. Literature Review

Several commercial groups has been working out on the similar projects and their working principles are much different than the e-VAB, because they are providing the information (visual signals) either through tongue using an electrode just like lolly popor by using a television camera and cluster of electrodes attached to the occipital lobes at the skull [3 - 4]. At the Massachusetts Institute of Technology's Cognitive and Brain Science Department, researchershave proposed to supply the electrical messages that the brain interprets as an "image" directly to the brainusing microelectrodes threaded carefully into the Visual Cortex [1].

IX. Resultsandanalysis

Implementation of such Visual Aid can enable the visually impaired persons to see a wide vision field and differentiate between the objects. This research can get its practical picture in Pakistan as the highly equipped laboratories for the Bio-material Microchip fabrication and neural implantsurgery facilities may be introduced.

X. Future Recommendations

The proposed e-VAB can provide images to the brain in gray scaleonly because of the lack of RGB which are present in the cones of the eyes. The system can be enhanced by providing the facility of colored visual signals.

XI. Acknowledgements

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Country: Pakistan

Design and Analysis of Substation Grounding System using Computer Aided Techniques

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Abstract:

Substation grounding systems have been receiving more attention in recent years due to economic and technical considerations. In earlier years the human safety was the most important consideration, but now the economics is equally important as well. So the design should be developed on such frame work which is user friendly and may provide different alternatives, so that the design could be made optimal.

In Pakistan the conventional methods of designing grounding system are still in practice, e.g. using manual calculations or work sheets. With the advent of modern technologies, there is a need to validate the new technology on actual grounding systems taking into consideration the actual system data or vice versa to check if the previously designed grounding systems satisfy the criteria of safety and economics. In this scenario we provide guidelines, elaborating the importance of a user-friendly technique, for the improvement in the design of a substation grounding system and for analyzing the effects of various parameters on the design using ETAP. The design has been validated by actual system parameters of 220 kV Ludewala Substation and 132 kV Jail Road Multan Substation. Cost analysis has been performed to select the optimal configuration.

1. INTRODUCTION

One of the most important designs in the construction of a substation is the design of its grounding system. The design of the substation grounding system is carried out in order to ensure the following tasks [1]:

- Safety of workers/personnel in the vicinity of grounded facilities. The touch and step voltage produced under a fault condition have to be at safe values. A safe value is one that will not produce enough current within a human body to cause ventricular fibrillation.
- Safety of equipment by carrying and dissipating fault currents to earth without exceeding any equipment limits.
- Reliable operation of protective devices by providing a low resistance path for protective relays to see and clear ground faults which improves protective equipment performance.

When a person has simultaneous contact with two surfaces which are at different potentials, step and touch voltages may arise. When the fault current flows through the grounding conductors, it is possible for a person to make simultaneous contact with two parts which are at different potential due to passage of the fault current. The flow of current may result in voltage gradients within and around the substation, not only between structures and nearby earth, but also along the ground surface [2]. In a properly designed system, this gradient should not exceed the limits that can be tolerated by the human body.

Ideally earth is considered as zero-potential surface. But due to soil resistivity, earth potential is not zero. Fault currents have also been increasing as more and more systems are being interconnected in order to fulfill the growing load demand. This may result in an increase in the grid-potential rise (GPR) in the events of faults. This voltage, GPR, is equal to the maximum grid current times the grid resistance as:

$$GPR = I_g \, x \, R_g$$

GPR is controlled by keeping the grid resistance as low as possible. A substation grounding system is designed to lower R_g. A substation grounding system consists of a mesh of grounding conductors which are horizontally buried in the earth and ground rods which are placed vertically in the grid. The mesh is connected to ground rods driven in ground, and to all metal structures and equipment in the substation. Additional ground rods are provided at the points where impulse discharges are expected. A final topping of gravel is provided in order to increase the tolerable limits of step voltage and touch voltage.

2. LITERATURE SURVEY

Design of the earthing system for a 220 kV substation and simulations for required parameters have been presented in reference [1]. The results have been obtained using MATLAB software. Graphs showing the relationships of grid resistance, step and touch voltage with soil resistivity, and conductor size with fault currents have been given. The user interactive approach, in MATLAB, has been developed for the design configuration and total required conductor length in reference [4]. The effect of soil stratification has also been discussed. Reference [5] discusses the effect of soil resistivity and ground rods on the value of GPR and it is evaluated that if top layer resistivity is more than that of the bottom layer the ground rods will greatly reduce the value of GPR. However, if top soil layer has less resistivity than that of the bottom layer the ground rods will slightly reduce GPR. Thus, due to different soil characteristics at every substation the ground grid design must carefully be done to gain acceptable safety as well as optimal investment.

Computer model for the design of grounding systems, conforming to IEEE standard, has been presented. The cases enlisted in the IEEE standard are used as reference point and the results of IEEE standard have been compared with CYMGRID [7].

The emphasis of our work is to utilize ETAP for the improvement of grounding system design for existing and new substations. We have fed the actual data of existing 132 kV Jail Road Multan Substation and 220 kV Ludewala Substation into ETAP grounding grid module and performed simulations. The simulations reveal some discrepancies in the original designs of these substations. The cost analysis has been performed for different design alternatives to choose the optimal configuration. The detailed comprehensive parametric analysis has also been performed to know how various parameters would affect the design. The effect of surface layer resistivity and its thickness on the design has been elaborated.

3. STEP BY STEP PROCEDURE FOR GROUNDING SYSTEM DESIGN

Using manual calculations or excel sheets the following step by step procedure may be adopted:

Step 1: Collection of field data

Step 2: Size of grounding conductor

Step 3: Touch & step criteria

Step 4: Assume initial design

Step 5: Calculation of GPR = $I_g \times R_g$

Step 6: Safe design verification.

DESIGN OF THE GROUNDING SYSTEM USING ETAP

ETAP grounding grid module presents three views; soil view, top view and 3-D view. The 3-D view is used for the three-dimensional display of the grounding grid. The design data are entered in soil view and top view.

Soil Model: The surface layer resistivity, soil resistivity and thickness of surface layer are added in 'soil model'.

Top Model: The data for the conductor and earth rod are entered.

The data entered in the ETAP software regarding 220 kV Ludewala Substation are given in tables I, II and III.

Table I: Soil related data for 220 kV Ludewala Substation.

1.	Soil resistivity	ρ	:	20	Ω-m
2.	Gravel resistivity	ρ_s	:	3000	Ω-m
3.	Thickness of gravel	h_s	:	0.2	m

Table II: Conductor data for 220 kV Ludewala Substation.

1.	Grid Size (L_x x L_y)	220 m x 145 m (475.7 ft x 721.8 ft)
2.	No. of conductor in x-direction	12
3.	No. of conductor in y-direction	8
4.	Conductors depth	2.3 ft
5.	Conductor size	236 kcmil
6.	Type of conductor	Copper Annealed soft drawn

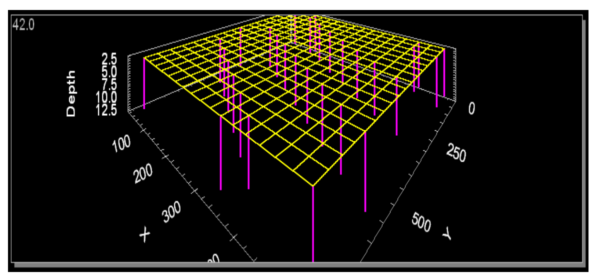
Table III. Grounding rod data for 220 kV Ludewala Substation.

1.	No. of rods	30
2.	Diameter of rods	0.63 inch
3.	Length of rod	9.84 ft
4.	Arrangement	Rods throughout grid area
5.	Type of rod	Copper clad steel rod

The simulations were performed for the following values:

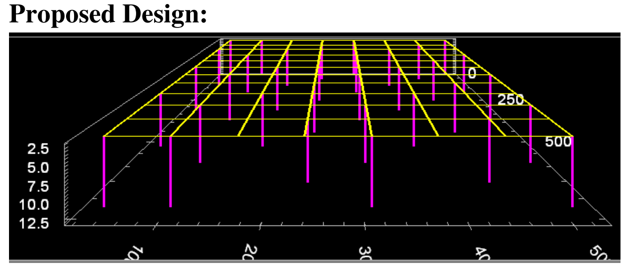
1.	Symmetrical short circuit current	I_f	:	40	kA
2.	Duration of fault current	t_s	:	1	sec

Existing Design:



Number of conductors in x-axis = 18
Number of conductors in y-axis = 17
Total length of the conductor = 6350 m
Number of the earth rods = 30
Total length of earth rods = 90 m

Proposed Design:



Number of conductors in x-axis = 12
Number of conductors in y-axis = 8
Total length of the conductor = 3500 m
Number of the earth rods = 30
Total length of the earth rods = 90 m

Results Obtained:

Ludewala Substation	Tolerable Values	Existing	Proposed
Step Voltage	734.6 V	219.6 V	334.3 V
Touch voltage	2467.3 V	106.5 V	111.2 V

Cost Comparison:

The ration of the actual design cost to the proposed design cost is 1.814. The step and touch voltages are within limits, whereas the cost is greatly reduced.

132 kV Jail Road Multan Substation:

The data are given in tables IV, V and VI.

Table IV: Soil data for 132 kV substation.

1.	Soil resistivity	ρ	:	86.8	Ω-m
2.	Gravel resistivity	ρ_s	:	3000	Ω-m
3.	Thickness of gravel	h_s	:	0.15	m

Table V: Conductor data for 132 kV substation.

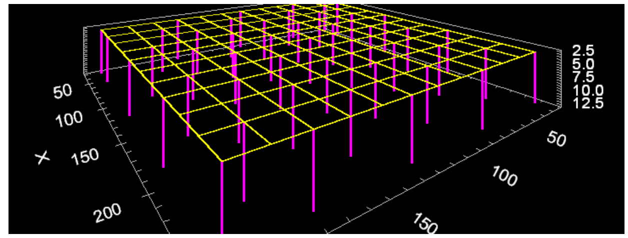
1.	Grid Size (L_x x L_y)	65 m x 59 m
2.	No. of conductor in	17
3.	No. of conductor in y-direction	19
4.	Conductors depth	2.63
5.	Conductor size	188 kcmil
6.	Type of conductor	Copper Annealed soft

Table VI: Grounding rod data for 132 kV substation.

1.	Number of rods	38
2.	Diameter of rods	0.63 inch
3.	Length of rod	9.84 ft
4.	Arrangement	Rods throughout grid area
5.	Type of rod	Copper clad steel rod

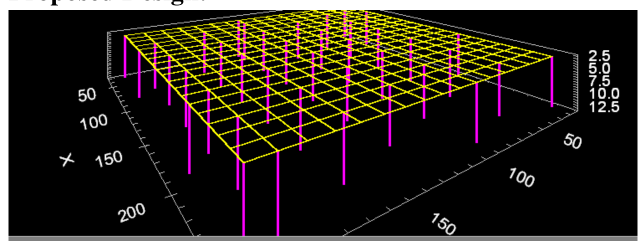
Simulations were performed for 40 kA fault current of 1 sec duration.

Existing Design:



Number of conductors in x-axis = 12
Number of conductors in y-axis = 11
Total length of conductor = 1429 m
Number of earth rods = 38
Total length of earth rods = 114 m

Proposed Design:



Number of conductors in x-axis = 17
Number of conductors in y-axis = 19
Total length of conductor = 2226 m
Number of earth rods = 38
Total length of earth rods = 114 m

Results Obtained:

Jail Road Substation	Tolerable Values	Actual	Proposed
Step Voltage	734.6 V	988.1 V	690.3 V
Touch voltage	2467.3 V	607 V	673.3 V

Cost Comparison:

The ration of the actual design cost to the proposed design cost is 0.64.

In this case the cost of the proposed design will be higher, but the design will become safe and within tolerable limits.

4. PARAMETRIC ANALYSIS

The following parameters mainly affect the grounding system design calculations:

- Soil resistivity
- Fault current
- Thickness of surface layer/ gravel
- Surface layer resistivity

The analysis has been carried out for the design of 132 Jail Road Substation.

The soil resistivity and fault current affect the calculated touch and step voltages [3].

$$E_{step} = \frac{\rho.K_s.K_i.I_G}{L_s}$$

$$E_{touch} = \frac{\rho.K_m.K_i.I_G}{L_M}$$

4.1 Effect of Soil Resistivity

Tolerable touch Voltage = 707.1 V

Tolerable step Voltage = 2357.4 V

The effect is shown in Table VII.

Table VII: The effect of soil resitivity on 132 kV substation.

Surface layer resistivity $=\rho_s$	3000 Ω	3000 Ω	3000 Ω
Soil resistivity= ρ	40 Ω	86.8 Ω	120 Ω
Calculated touch Voltage, V	318.1	690.3	954.3
Calculated step Voltage, V	310.3	673.3	930.8
GPR, V	3461.4	7511.2	10384.2

4.2 Effect of Fault Current

Tolerable touch Voltage = 707.1 V

Tolerable step Voltage = 2357.4 V

The effect is shown in Table VIII.

Table VIII: The effect of fault current on 132 kV substation.

Surface layer resistivity $=\rho_s$	3000 Ω	3000 Ω
Soil resistivity= ρ	86.8 Ω	86.8 Ω
Fault current	40 kA	20 kA
Touch Voltage, V	690.3	345.1
Step Voltage, V	673.3	336.6
GPR, V	7511.2	3755.6

4.3 Effect of Surface Layer Resistivity

Surface layer resistivity and its thickness affect the tolerable limits of step and touch voltages [3].

$E_{step} = (1000 + 6C_s.\rho_s)\ 0.157/\sqrt{ts}$

$E_{touch} = (1000 + 1.5C_s.\rho_s)\ 0.157/\sqrt{ts}$

The calculated touch voltage is 690.3 V and the calculated step voltage is 673.3 V.

Surface layer resistivity $=\rho_s$	3000 Ω	5000 Ω	8000 Ω
Soil resistivity= ρ	86.8 Ω	86.8 Ω	86.8 Ω
Tolerable touch Voltage, V	707.1	1070.7	1616.2
Tolerable step Voltage, V	2357.4	3811.9	5993.7
GPR, V	7511.2	7511.2	7511.2

5.4 Effect of Surface Layer Thickness

Surface layer resistivity $=\rho_s$	3000 Ω	3000 Ω	3000 Ω
Soil resistivity= ρ	86.8 Ω	86.8 Ω	86.8 Ω
Thickness of surface layer	6″ = 0.5 ft	8″ = 0.667 ft	10″ = 0.833 ft
Tolerable touch Voltage, V	707.1	739.2	760.2
Tolerable step Voltage, V	2357.4	2485.7	2569.8
GPR, V	7511.2	7511.2	7511.2

5. CONCLUSIONS

A user-friendly technique is very helpful for the optimum design of a substation grounding system. Technical and financial discrepancies associated with earlier substations grounding designs, using manual calculations, can be sorted out with the help of computer aided techniques. Parameters of every substation are different from those of other substations so the earthing system design calculations should be performed for every new substation. Recalculations should be carried out when:

- Fault level exceeds a certain limit.
- Soil resistivity may change with the passage of time due to dryness of soil. Therefore, soil resistivity measurements should be carried out periodically as well as grounding system parameters should be checked.
- Surface layer resistivity measurement should be carried out and actual values should be used for grounding system design calculations.

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Quotation

- Laughter is tranquilizer with no side effect.
  Arnold Glasgow
- Laughter is the form of internal jogging. It moves your internal organs around. It enhances respiration. It is an igniter of great expectations.
  Norman Cousins
- Laugh and the world laughs with you; weep and you weep alone.
  Ella Wheer Wilcox
- The most wasted of all our days are those in which we have not laughed.
  Sebastien Chamfort
- My way of joking is to tell the truth; it's funniest joke in the world.
  George Bernard Shaw
- A man may die, nations may rise and fall, but an idea lives on. Ideas have endurance without death.
  John F. Kennedy
- A stand can be made against invasion by an army; no stand can be made against invasion by an idea..
  Victor Hugo
- There is one thing stronger than all the armies in the world; an idea whose time has come.
  Victor Hugo
- An idea that is not dangerous is not worthy of being called an idea at all.
  Oscar Wilde
- The realization of ignorance is the first act of knowing.
  Jean Toomer
- Violence is a tool of the ignorant.
  Flip Wilson
- Fear always springs from ignorance.
  Ralph Waldo Emerson
- Ignorance is the night of the mind, a night without moon or star.
  Confucius
- If we lacked imagination enough to force something better, life would indeed be a tragedy.
  Laurence J. peter

Evaluation of SSSC and Statcom Facts Devices Application in Power Systems (Part-I)

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1. Introduction

An electrical power system consists of sources that generate power and loads that are required by the customer. An arrangement of transformers, transmission lines and additional equipments are used for their inter-connection. A lot of variations are present in the structure of the power system which are mainly influenced by economic, political engineering and environmental decisions.

2. Flexible alternating current transmission Systems

Several decades ago, the earliest solid state power control device was developed with the thyristor being the basic switching tool. The technology has undergone a number of changes with the passage of time, in such a way that the power appliances have become very competent to utilize their capability in order to cause an affect on any of the three main factors of control system (voltage, impedance and phase angle) [1].

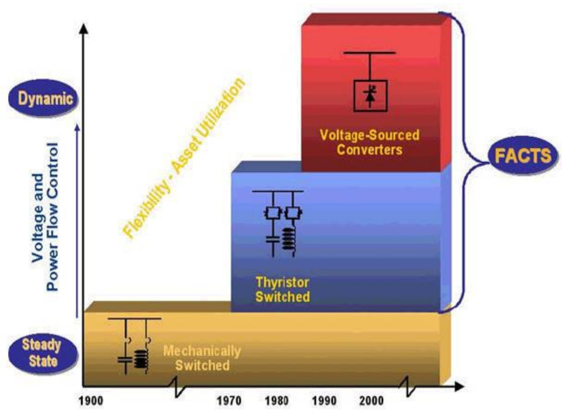

Figure 1: Evolution of Electronic Devices [1].

When the development program of FACTS technology was initialized, it was realized then and there that there was a need for the up gradation of most, if not all, of the system investigation utensils which were being employed by the power engineers for operation and maintenance of the transmission system so as to evaluate the usefulness of these controllers on a large scale basis. Great attention in the field of research has been received by the following in this case: [2];

- Dynamic stability
- Three-phase power flow
- Power quality
- Transient stability
- State estimation
- Optimal power flow
- Electromagnetic transients
- Positive sequence power flow

The following characteristics are possessed by FACTS devices [3];

- **Improve system stability.**
- **Control real and reactive power flow.**
- **Mitigate potential Sub-Synchronous Resonance problems**
- **Provide dynamic reactive power support and voltage control.**
- **Reduce the need for construction of new transmission lines, capacitors, reactors, etc.**

3. Inherent limitations of Transmission System

The characteristics of a given power system evolve with the growth of load and addition of generation. Incase the services of the transmission system are not improved adequately; the transient stability and steady-state issue of the power system are greatly exposed [4].

Following limitations are faced by a power system during power transmission (Song and Johns, 1999):

- thermal limit
- voltage limit
- stability limit
- angular stability
- transient stability
- dynamic stability

Thermal limit is the major restraining issue in a transmission system. The transmission line may sag down and may contact trees if the thermal limit of the system is exceeded. This limit is surpassed because of the generation of heat due to current in the transmission lines. If the system is being used to its maximum capacity that means that the functioning of the system is in close proximity with its thermal limit. This is hardly the case, however, because the capability of the transmission system is restricted by the limits provided by voltage and stability. If the power system is operating within a particular period, such as ±5 percent of the nominal voltage, then normally in that case the voltage limit is maintained.

Stability can be divided into two categories [14]:

3.1 Fast phenomena

Fast occurrences are referred to as transient or angular stability. The example can be taken that of lightening which causes the voltage to faults in the transmission system [4].

3.2 Slow phenomena

Slower occurrences are referred to as dynamic stability. Consider the example of switching of lines or power oscillations which are produced due to detachment of huge quantity of load or generation [4].

By using FACTS technologies, possibilities can be created so that the system can be operated nearer to the thermal limits provided by the system. In this way, we can obtain solution to all the above mentioned stability and voltage issues [4].

4. Benefits of FACTS Devices [5]

Following benefits are provided by FACTS devices [5]:

- **Rapidly Implemented Installations**
  Projects utilizing FACTS devices are quickly installed at existing substations hence no requirement for constructing new transmission lines and therefore there is no necessity for acquiring public or private lands [5].
- **Increased System Capacity**

  Increment in capacity on the already existing power system is provided by FACTS devices. This is done by permitting highest equipped competence of the already present transmission lines and other utensils [5].
- **Enhanced System Reliability**
  Strengthening of transmission systems is provided by FACTS, as a result acquiring more voltage stability and increased power flow control. This improvement leads to superior system reliability and safety[5].
- **Improved System Controllability**
  The phenomenon “intelligence” is build into the power system by FACTS which leads to improved system controllability so as to acquire the ability to respond quickly to any disturbance taking place in the system and avoiding any gridlock constraints. [5]
- **Seamless System Interconnections**
  “Seamless” interconnections can be established by BTB (back-to-back) dc-link configurations employed by FACTS between and within local and regional networks. This allows power transfer control and an improvement in the stability of grid [5].
- **Environmental Benefits**
  FACTS devices are environmentally friendly in such a way that there are no harmful equipment and no pollutants or waste material produced by them. Electrical energy is distributed more economically with the help of FACTS devices by using improved deployment of already present installations and in this way the need for the construction of new transmission lines is decreased [5].

5. Proper Location for FACTS Devices:

When considering the design of FACTS controllers, the significant feature that should be taken into consideration is appropriate type of place. The design and synchronization of their controllers can be carried out by depending upon the location of FACTS. As discussed in last sections, FACTS devices are able to modify the parameters of the power system in a swift and efficient manner. Thus, in this way the benefits that occur due to utilization of FACTS devices include enhancement of system reliability, reduction of operation investment cost, improvement of system stability, and diminution of transmission speculation price [6].

6. Power system Stability

One of the important problems for safe operation of the transmission system is the stability of that system. This significance of this event has been demonstrated by a number of major blackouts that took place due to the instability of the transmission system. Employment of latest control techniques and technologies, amplified procedure during situations of great stress and a number of types of instabilities in the power system have materialized with the process of evolution of power systems through continuous expansion in interconnections [7].

6.1 Definition of Power System Stability

Power system stability is defined as the ability of the electric power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance [2,8].

6.2 Types of Power System Stability

Different types of power system stability are:

6.2.1 Transient Stability

When the transmission system is subjected to a rigorous transient disturbance, then the capability of the system to maintain its state of synchronism is called transient stability of that transmission system. [9,10].

6.2.2 Small Signal Stability

Oscillations of low frequencies are used to illustrate small signal stability and they are of two different kinds. One type of such oscillations are known as “inter-area mode” oscillations whose frequencies lie in the range of 0.1 to 0.7 Hz. The second type of oscillations are called “local plant mode” oscillations. In this case the frequency lies in the range of 0.8 to 2.0 Hz. [9,11].

6.2.3 Voltage Stability

When a transmission system sustains the value of all bus voltages present in it when it is being operated under normal conditions and after the occurrence of any sort of disturbance, then this capability of the system is called its voltage stability. A few factors that are responsible to bring a system into a state of voltage instability are sudden increase in load demand, a change in system conditions causing a progressive and unmanageable drop in voltage and any other sort of disturbance [12].

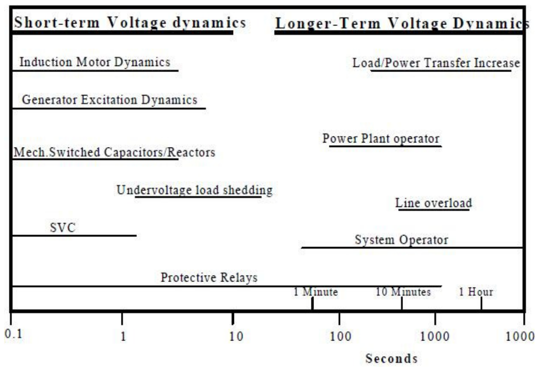

Figure 2: Time Duration of Disturbances affecting voltage Stability [13].

6.2.4 Rotor Angle Stability

The capability of synchronous machines to maintain a state of synchronism after an event of disturbance is called rotor angle stability.

6.2.5 Frequency Stability

Frequency stability is of two types namely short term and long term. It is the ability and property to maintain a constant frequency after the occurrence of an interruption whos time interval may be of short or long duration[14].

Table 1: Power Quality Problems and Causes [14].

BROAD CATEGORIES	SPECIFIC CATEGORIES	METHODS OF CHARACTERI-ZATION	TYPICAL CAUSES
Transients	Impulsive	Peak magnitude, rise time and duration	Lightening strike, transformer energization, capacitor switching
	Oscillatory	Peak magnitude, frequency components	Line or capacitor or load switching
Short duration voltage variation	Sag	Magnitude, duration	Ferroresonant transformers, single line-to-ground faults
	Swell	Magnitude, duration	Ferroresonant transformers, single line-to-ground faults
	Interruption	Duration	Temporary(self -clearing) faults
Long duration voltage variation	Undervoltage	Magnitude, duration	Switching on loads, capacitor de energization
	Overvoltage	Magnitude, duration	Switching on loads, capacitor energization
	Sustained interruptions	Duration	Faults
Voltage imbalance		Symmetrical components	Single-phase loads, single-phasing condition
Waveform distortion	Harmonics	THD, harmonic spectrum	Adjustable speed drives and other nonlinear loads
	Notching	THD, harmonic spectrum	Power electronic converters
	DC offset	Volts, Amps	Geo-magnetic disturbance, half-wave rectification
Voltage flicker		Frequency of occurrence, modulating frequency	Arc furnance, arc lamps

6.3 Power System Stabilizer (PSS)

Power system stabilizer is a conventional, cost-effective and a very valuable controller to used for the improvement of small signal stability. The installation of this apparatus takes place as an supplementary control in the excitation system of a generator. By modulating the generator excitation, PSS adds damping to the oscillations of the generator rotor [15].

6.4 Sub-synchronous Resonance (SSR)

The occurrence of SSR usually takes place in transmission lines by the compensation of a series capacitor. When the complement frequency of the system is in close proximity with one of torsional frequencies of turbine-generator shaft system then the occurrence of SSR takes place. Huge sub synchronous currents are produced by a small quantity of voltage that is induced by rotor oscillation. The rotor oscillations are increased by the phase of the oscillatory component of rotor torque which is produced by this current [15].

6.5 Power System Constraints

The limitations of the transmission system consist of [16];

a) Power System Oscillation Damping Limit
b) Thermal Limit
c) Short-Circuit Current Limit
d) Dynamic Voltage Limit
e) Voltage Stability Limit
f) Inadvertent Loop Flow Limit

g) Transient Stability Limit
h) Steady-State Power Transfer Limit
i) Others

A single or a number of the above stated constraints can be present in any transmission blockage or regional restraint. By undergoing a thorough analysis of systems manufacturing criteria, we can obtain the solution of the above stated issues in the most commercial and synchronized method [16].

6.6 Benefits of Control of Power Systems

The following are the benefits of control of power system [16];

- Added Flexibility in Sitting New Generation
- Added Power Flow Control
- Increased System Security
- Increased Loading and More Effective Use of Transmission Corridors
- Improved Power System Stability
- Elimination or Deferral of the Need for New Transmission Lines
- Increased System Reliability

The above mentioned advantages are vital to accomplish in the overall development and procedure of power systems.

7. Flexible AC Transmission system (FACTs)

Appliance of advanced control technologies results in better consumption of the existing power system. Instead of construction of new transmission lines, FACTS technologies allow for enhanced transmission system procedure with minimal implementation time, environmental impact and infrastructure investment [17].

7.1 FACTS Technology

FACTS technologies can be divided into the following two categories:

7.1.1 Series Compensation

FACTS is connected in series with the power system in series compensation.

Tasks of series compensation are [18];

- Reduction of system transfer impedance
- Damping of active power oscillations
- Reduction of load dependent voltage drops
- Increase of system stability
- Load flow control for specified power paths
- Reduction of transmission angle [18].

The following figure shows different series compensation configurations and their effects on short circuit level and phase angle:

7.1.2 Shunt Compensation

In shunt compensation, power system is connected in shunt with the FACTS.

Tasks of dynamic shunt compensation are [18]:

- Improvement of system stability
- Steady-state and dynamic voltage control
- Damping of active power oscillations
- Reactive power control of dynamic loads

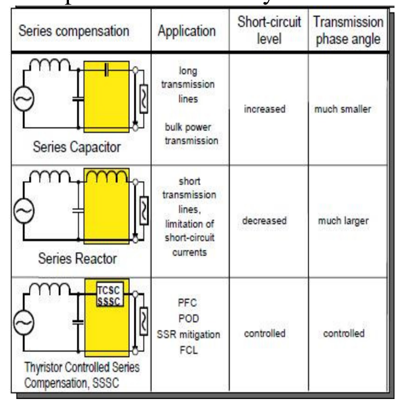

Figure 3: Types of Reactive Power Series Compensation and Application [18].

There are two types of Shunt compensation techniques.

7.1.2.1 Shunt Capacitive Compensation

Power factor is improved using this method. Due to lagging load current, power factor also lags when an inductive load is connected to the transmission line. A shunt capacitor is used to draw current which results in leading the source voltage to compensate this. Thus, we get an enhancement in power factor in this way [18].

7.1.2.2 Shunt Inductive Compensation

This method is utilized under two conditions. The first one is when the transmission line is being charged. The second condition is when the load present at the receiving end is of very small amount. Voltage amplification (Ferranti Effect) is caused in the transmission line during shunt inductive compensation. Shunt inductors are connected across the transmission line for compensation [19].

The following figure shows different shunt compensation configurations and their effects on short circuit level and phase angle:

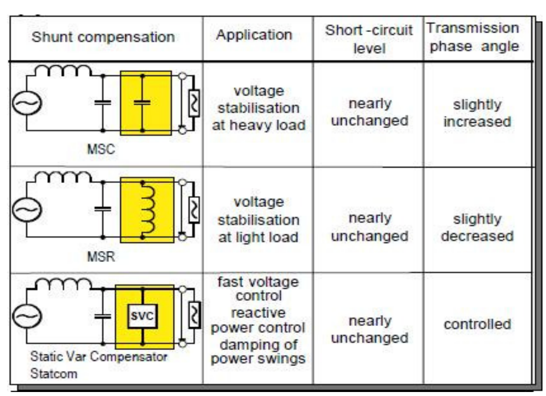

Figure.4: Types of Reactive Power Shunt

Compensation and Application [18].

7.2 Types of FACTS Controllers

Following are the different types of FACTS controllers [20]:

- series controllers
- shunt controllers
- combined series-series controllers
- combined series-shunt controllers

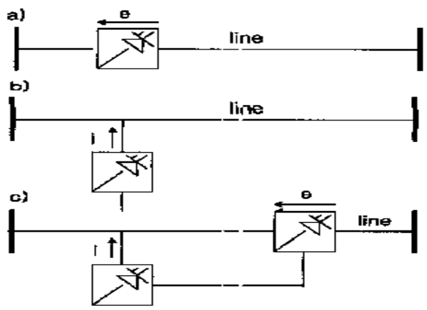

Figure 5: Basic Types of FACTS Device Series Controllers, b) Shunt Controllers, C)Combined Series-Shunt Controllers [20].

7.2.1 Principle of Series Controllers

A series controller may be considered as variable reactive or capacitive impedance. Its value is accustomed to damping of oscillations that occur in power system. By the injection of an appropriate voltage phasor which should be in series with the transmission line, this can be achieved. Reactive power is absorbed or controlled by the series controller if the line voltage is in phase quadrature with the line current. Otherwise, both real and reactive power are absorbed or produced by the controller. Alleviation of line overloads and increment in transfer capability can also be done with the help of a series controller [21].

Examples:
Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Reactor (TCSR).

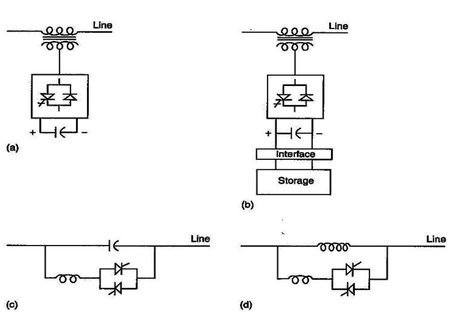

Figure 6: Examples of Series Controllers.

a) Static Synchronous Series Compensator(SSSC), b) SSSC with storage, c) Thyristor-Controlled Series Capacitor(TCSC) and Thyristor-Switched Series Capacitor(TSSC), (d)Thyristor-Controlled Series Reactor(TCSR) and Thyristor-Switched Series Reactor(TSSR) [21].

7.2.2 Principle of Shunt Controllers

Current is injected into the system at the point where the shunt controllers are inter-connected with the transmission system. A variable current flow is caused by a variable shunt impedance by the injection of current into the system. Reactive power is adjusted by the shunt controller if the injected current and the line voltage are in phase-quadrature with each other. If this is not the case then real power is adjusted by the controller. At the voltage bus, if the reactive power is injected then the voltage can be compensated by the shunt controller [21].

Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC).

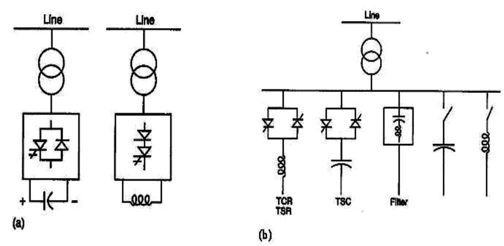

Figure 7: Examples of Shunt Controllers.

a) Static Synchronous Compensator(STATCOM) based on voltage-sourced and current-sourced convertereries Controllers, b) Static VAR Compensator(SVC), Static VAR Generator(SVG), Static VAR System(SVS), Thyristo-Controlled Reactor(TCR), Thyristor-Switched Capacitor(TSC), and Thyristor Switched Reactor(TSR) [21].

7.2.3 Principle of Combined Series-Series Controllers

Two configurations can be considered in case of combined series-series controller. In the first configuration, series controllers are being operated in a synchronized behavior in a multiline transmission system. In the second configuration, there is independent reactive power control for each line of a multiline transmission system. Facilitation of real power transfer through the power link also takes place at the same time [21].

Interline Power Flow Controller (IPFC).

7.2.4 Principle of Combined Series-Shunt Controllers

Here again two different configurations can be considered. The first one consists of two separate series and shunt controllers that operate in a coordinated manner. The second configuration consists of an interconnected system of series and shunt components. Current is injected into the system by the shunt component and voltage by series component in each configuration. When these two elements are unified, a real power can be exchanged between them via the power link. The release of power flow conjestion and voltage support can be achieved by the utilization of these controllers as the features of both series and shunt controllers are combined in this case [21].

Examples:

Thyristor-Controlled Phase-Shifting Transformer (TCPST) , UPFC.

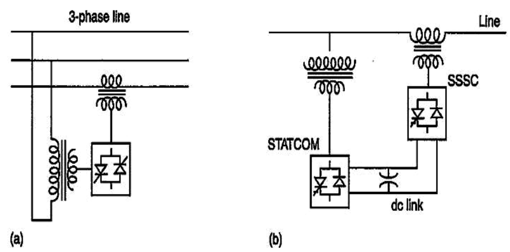

Figure 8: Examples of Combined Series-Shunt Controllers [21].

a) Thyristor-Controlled Phase Shifting Transformer(TCPST) or Thyristor- Controlled Phase Angel Regulator(TCPR),
b) Unified Power Flow Controller (UPFC)[21].

7.3 Classification of FACTS Devices

FACTS devices can also be classified as:

7.3.1 Variable impedance type

This category includes the following FACTS devices [21]:

(i) Shunt connected---Static Var Compensator (SVC).

(ii) Series connected---Thyrister Controlled Series Capacitor or compensator (TCSC).

(iii) Combined shunt and series---Thyristor Controlled Phase Shifting Transformer (TCPST) of Static PST.

7.3.2 Voltage Source Converter (VSC) – based

FACTS devices included in this category are:

(i) Shunt connected---Static synchronous Compensator (STATCOM)

(ii) Series connected---Static Synchronous Series Compensator (SSSC)

(iii) Combined series-series---Interline Power Flow Controller (IPFC)

(iv) Combined shunt-series---Unified Power Flow Controller (UPFC)

There are several advantages that VSC based FACTS controllers have over the variable impedance type. Considering an example, for similar rating of STATCOM and SVC, STATCOM is much more compact and technically superior. Also, active power can also be supplied by STATCOM under the condition that an energy source is present or large energy storage at its DC terminals [21].

7.4 Applications and Technical Benefits of FACTS Devices

The following figure and table describe the technical benefits of the principal FACTS devices including steady state applications in addressing problems of thermal limits, voltage limits, short circuit levels, sub synchronous resonance and loop flows.

	Load Flow Control	Voltage Control	Transient Stability	Dynamic Stability
SVC	●	●●●	●	●●
STATCOM	●	●●●	●●	●●
TCSC	●●	●	●●●	●●
UPFC	●●●	●●●	●●	●●

●
●●
●●● Better

Figure 9: Benefits of FACTS devices [22].

7.5 Worldwide Applications of FACTS Devices

Listed below are some of the many projects where FACTS devices have proven their benefits over several years [22]:

Australian interconnector.

- South Africa: increase in line capacity with SVC.
- Brazil: North-South interconnection.
- USA: More effective long-distance HVDC-System.
- Indonesia: Containerized Design
- USA: the Lugo SSR Damper
- USA: the Kayenta TCSC

Table 2: Steady state applications of FACTS [23].

Issue	Problem	Corrective Action	Conventional solution	FACTS device
Voltage limits	Low voltage at heavy load	Supply reactive power	Shunt capacitor, Series capacitor	SVC, TCSC, STATCOM
	High voltage at light load	Remove reactive power supply	Switch EHV line and/or shunt capacitor	SVC, TCSC, STATCOM
		Absorb reactive power	Switch shunt capacitor, shunt reactor	SVC, STATCOM
	High voltage following outage	Absorb reactive power	Add shunt reactor	SVC, STATCOM
		Protect equipment	Add arrestor	SVC
	Low voltage following outage	Supply reactive power	Switch shunt capacitor, reactor, series capacitor	SVC, STATCOM
		Prevent overload	Series reactor, PAR	TCPAR, TCSC
	Low voltage and overload	Supply reactive power and limit overload	Combination of two or more devices	TCSC, UPFC, STATCOM, SVC
Thermal limits	Line or transformer overload	Reduce overload	Add line or transformer	TCSC, UPFC, TCPAR
			Add series reactor	SVC, TCSC
	Tripping of parallel circuit (line)	Limit circuit (line) loading	Add series reactor, capacitor	UPFC, TCSC
Loop flows	Parallel line load sharing	Adjust series reactance	Add series capacitor/reactor	UPFC, TCSC
		Adjust phase angle	Add PAR	TCPAR, UPFC
	Post-fault sharing	Rearrange network or use "Thermal limit" actions	PAR, Series Capacitor/Reactor	TCSC, UPFC, SVC, TCPAR
	Flow direction reversal	Adjust phase angle	PAR	TCPAR, UPFC
Short circuit levels	Excessive breaker fault current	Limit short circuit current	Add series reactor, new circuit breaker	SCCL, UPFC, TCSC
		Change circuit breaker	Add new circuit breaker	
		Rearrange network	Split bus	
Subsynchronous resonance	Potential turbine /generator shaft damage	Mitigate oscillations	series compensation	NGH, TCSC

Legend for Exhibit 3

NGH = Hingorani Damper
PAR = Phase-Angle-Regulator
SCCL = Super-Conducting Current Limiter
SVC = Static Var Compensator
STATCOM = Static Compensator
TCPAR = Thyristor Controlled Phase-Angle Regulator
TCSC = Thyristor Controlled Series Capacitor
TCVL = Thyristor Controlled Voltage Limiter
TSBR = Thyristor Switched Braking Resistor
TSSC = Thyristor Switched Series Capacitor
UPFC = Unified Power Flow Controller

8. Synchronous Compensator (SATTCOM)

The Static Synchronous Compensator (STATCOM) is a shunt FACTS device. The main features of STATCOM are power flow control and improvement in transient stability in power electronics [2,3].

8.1 General Performance

Attaining a balance in the supply and demand of active and reactive power is essential in a power system. The collapse of the power system may take place if the required balance is lost. Proper voltage and reactive power control is one of the most significant feature for secure power system procedure. Rapid and constant capacitive and inductive reactive power supply is provided by STATCOM to the transmission system [24].

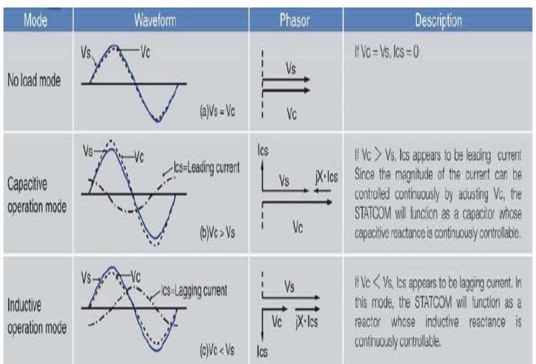

Figure10: STATCOM Operation Mode [24].

8.3 STATCOM Model

8.3.1 Basic Operation

The main components that constitute a STATCOM include a voltage-sourced inverter, coupling transformer and a dc capacitor. Mostly reactive power is exchanged between STATCOM and the ac system [25].

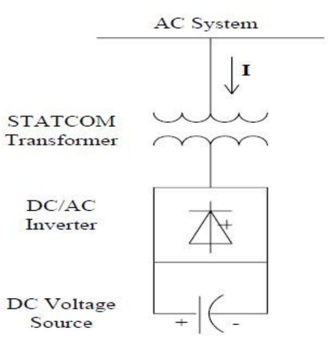

Figure 11: Functional Model of STATCOM [25].

The following points summarize the STATCOM operation:

- If Vstatcom = Vsystem, reactive current= zero →STATCOM does not generate/ absorb reactive power.
- If Vstatcom > Vsystem, current flows from STATCOM to the ac system → STACOM generates reactive power (capacitive).
- lf Vstatcom < Vsystem, current flows from the ac system to STATCOM →STATCOM absorbs reactive power (inductive).

The voltage of the ac system and the output voltage of STATCOM are in phase as only reactive power is being generated/absorbed by STATCOM [25].

8.3.2 Principle of Reactive Power Control

The amount of type of reactive power (capacitive or inductive) exchange taking place amongst the power system and STATCOM can be found out by the calculation of voltage of system with respect to that of STATCOM output voltage. The formula stated below is sued for showing the reactive power supplied by the STATCOM [25]:

$$Q = \frac{V_{STATCOM} - V_S}{X} V_S$$

Where

Vs = magnitude of system voltage

Vstatcom = magnitude of output voltage of STATCOM.

Q = Reactive power.

X = Equivalent impedance between STATCOM and the system.

Reactive power is supplied by STATCOM when Q has a positive value. On the contrary basis, reactive power is absorbed by STATCOM with Q possessing a negative value [25].

8.3.3 Simulation Modeling

The output waveform is shaped by using an inverter which is voltage sourced and three-phase. Six thyristors switches are used to constitute the inverter. The dc sourced energy charged is maintained by using six diodes. A transformer is used to connect the inverter bridge and diodes bridge to the grid which are interconnected also. This can be seen from the following figure:

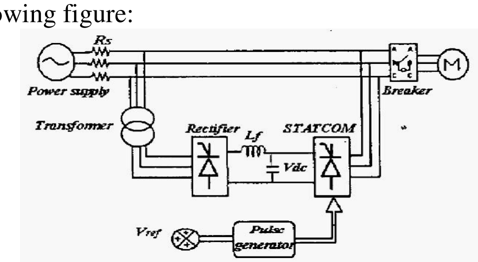

Figure 12: Simulation Model of STATCOM [25].

Current is injected into the system by the inverter bridge.when the voltage of STATCOM is greater than the system voltage, reactive power is supplied to the system. In the opposite case, when the system voltage is greater than voltage of STATCOM then reactive power will be absorbed from the system. This is represented by the following figure:

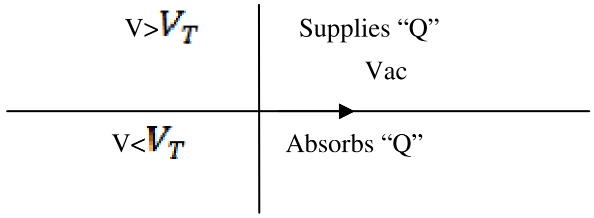

Figure 13: Generation and Absorption Reactive Power [25].

8.3.4 STATCOM V-I Characteristics

The two modes in which the STATCOM operation takes place are as follows:

- In voltage regulation mode
- In var control mode

During its operation in the voltage regulation mode, the following V-I characteristics are implemented by STATCOM.

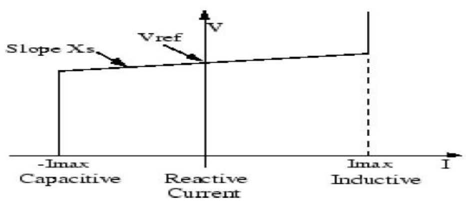

Figure 14: STATCOM V-I Characteristics [23]:

The regulated voltage is at Vref which is the reference voltage when the reactive current stays within the ratings of the converter, which are minimum and minimum current values (-Imax, Imax). The following equation is used to describe the V-I characteristics in this mode: [23].

V = Vref + Xs . I

where

V Positive sequence voltage (pu)

Vref Reference voltage (pu)

Xs Slope or droop reactance (pu/Pnom)

I Reactive current (pu/Pnom)

8.3.5 STATCOM Features

- Damping of power system oscillations
- Reduction of rapid voltages fluctuations (flicker control)
- Improvement of steady-state power transfer capacity
- Improvement of transient stability margin
- Reduction of temporary over-voltages
- Damping of sub synchronous oscillations
- Balanced loading of individual phases
- Effective voltages regulation and control
- Reactive compensation of AC-DC converters and HVDC links

9. Static Synchronous series compensator (SSSC)

The Static Synchronous Series Compensator (SSSC) is a series FACTS device. Its main features include power flow control and improvement in damping of power oscillations on grids [26].

9.1 General Performance

The SSSC is a static synchronous generator which operates as a series compensator. It injects a voltage in series with line current. Its output voltage is controlled independent of line current. It controls the transmitted power by decreasing or increasing the overall reactive voltage drop across the line. When the line current and injected voltage are in phase quadrature with each other, only reactive power is absorbed or transmitted by the series compensator. The injected output voltage of VSC acts as an ac voltage source. The line current is represented by the current flowing through the VSC [27].

Figure below shows the SSSC schematic diagram.

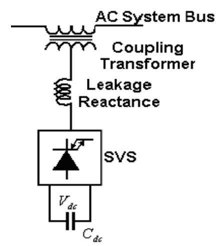

Figure 15: SSSC schematic diagram [27].

The leakage reactance of the step-down transformer forms reactance in series with ac/dc converter. The SSSC is connected in series with the transmission line [27].

If we consider the equivalent circuit of a SSSC compensated system, we can observe that a voltage source and impedence (Lr, Rr) are used to represent SSSC. SSSC is connected between buses 1 and 2. The line is represented by the pair (L1, R) and a transformer is represented by L2.

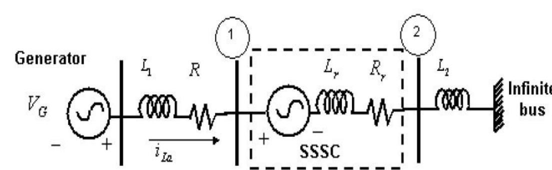

Figure 16: Equivalent circuit of SSSC compensated system [27].

V-I characteristics of SSSC can be seen from the following figure:

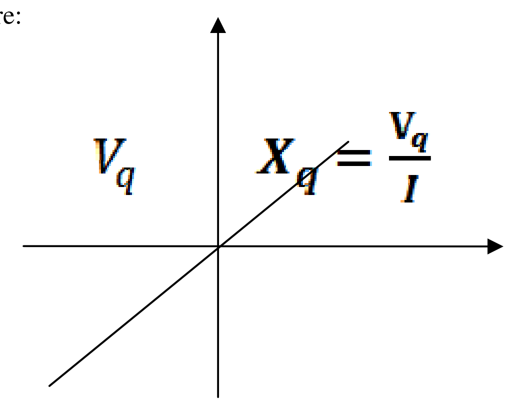

Figure 17: V-I characteristics of SSSC [27].

9.2 SSSC Features [27]

- The main feature of SSSC is power oscillation damping.
- It is able to internally generate a controllable voltage over same capacitive and inductive range which is not dependent on the magnitude of line current.
- To compensate for line resistance, real power is injected and in order to compensate for line reactance, reactive power is injected. In this way SSSC has the capacity to interface with external dc power supply.
- Real power is transmitted between SSSC and the ac system when the injected voltage and line current are not in quadrature with each other. The dc capacitor is charged or discharged in this way.

10. Conclusions

FACTS devices have gained a lot of importance to increase stability and power transfer capability for the better utilization of the existing power system due to deregulation of electricity market, new loading and power flow conditions.

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