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Engineering

# A HANDS-ON LABORATORY POWER SYSTEM STABILITY PRACTICAL APPROACHES USING POWER LINE SERIES COMPENSATOR

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**ABSTRACT** This paper aim to provide the readers with practical training techniques that explain the concepts of essential variables in the field of Power Systems Stability Education. Furthermore to improve the knowledge and performance in the real time operation of electrical network system. The practical approaches take the advantage of using the advanced Power Line Compensator equipment console box to simulate actual power line and collect data. The experimental approaches concentrated on the study of the voltage regulation and power system stability by tracing the voltage and power angle. Moreover to solve the difficulty in conceive the relations between different variables in the theoretical equation; therefore, a scenario of switching operation created for this purpose. Furthermore, the tables and line charts used for the collected data were helpful in the analysis of data, contribute in simplifying the problem in attractive way, and fulfill the challenge of visualizing the theoretical equations. Moreover this paper explained how the laboratory emulating equipment can be utilized in training and education programs for real-time power system control and design the training programs to meet the goals of professional training.

**KEYWORDS :** power network training and education, power system stability, emulation of real-time power lines, power angle, and voltage regulation.

## 1. INTRODUCTION:

1.1 Introduction to voltage regulation and power stability related to power transmission lines and its scientific theories.

The understanding cases related to power system stability at steady-state problems is one of the significant cases in the field of power generation and distribution sectors. Let's consider a synchronous non-salient generator connected to infinite bus as a sample power system as shown in fig. (1).The turbine produces mechanical torque $T_m$ controlled by the steam flow supplied by the boiler. The mechanical torque converted to electromagnetic torque $T_e$ through the interaction between the stator coils and the magnetic field of the rotor which generated by DC excitation current. The generated power $P_G$ ($P_e = T_e.w_m$) delivered to infinite bus, can be expressed by the equation

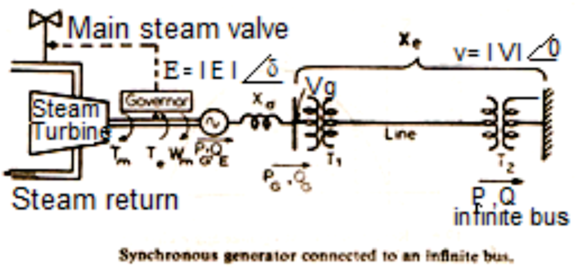


**fig. (1) Synchronous generator connected to infinite bus**

1.1 Relation between generated active power and power angle.

One of the important curves, which shows the Active power (MW) versus power angle characteristics for non-salient pole generator, connected to infinite bus as shown in fig. (2),

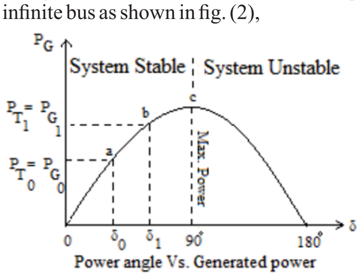


**Fig. (2): relation between generated power and power angle**

As the generated power increased from PT 0 to PT 1 the power angle also will increase accordingly. Until reach, the maximum steady state transfer power at 90 degree (System Stable zone).

1.1 Introduction to voltage regulation and power stability related to power transmission lines and its scientific theories.

The relations between different variables illustrated in the phasor diagram fig. (3) Such as terminal voltage, generated voltage, phase angle and power angle, where the resistance of the generator, shut admittance of the line and transformers were neglected. The generated power equation will be

$$P_G = |E|\,|I| \cos(\phi+\delta)$$

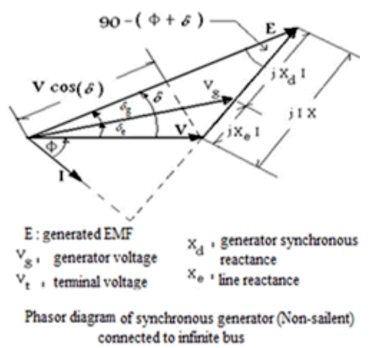


**fig. (3) phasor diagram of synchronous generator connected to infinite bus**

This paper focus on the power angle and terminal voltage variation with respect to load and compensation comparing the experimental results with the theoretical equation and phasor diagram. In addition, adding a value to the educational concepts in the field of power system stability.

1.1 Brief information about "LabVolt Power Line series compensation Demonstrator"

The Power Line Series Compensation Demonstrator is specifically designed for hands-on training in the principles of series compensation for electric power transmission lines. All equipment is provided in a single, integrated mobile console. [2]

The unit is powered from a standard single-phase ac wall outlet. It simulates two high-voltage (735 kV) three-phase transmission lines: one uncompensated 200km, and the other 300 Km compensated to 17%, 25%, or 34%. Line voltage, current, active power, and reactive power are measured at the inputs and outputs of the lines. The module is available at 220 V 50 Hz fig. (4).[2]

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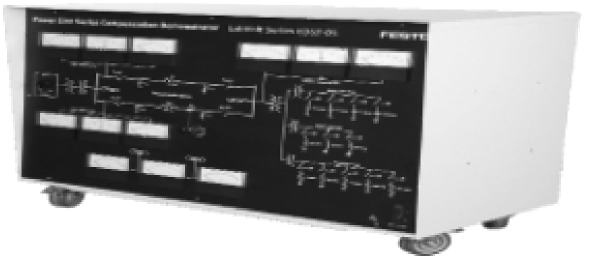


**Fig. (4): Power Line series Compensator Demonstrator**

Topic Coverage in this equipment

- Power Transfer Capability of a Transmission Line
- Effects of Series Compensation on Power Transfer Capability and System Stability
- Effect of Series Compensation on Regulation of the Receiver Voltage
- Reduction of Transmission Losses on Parallel Lines Using Series Compensation

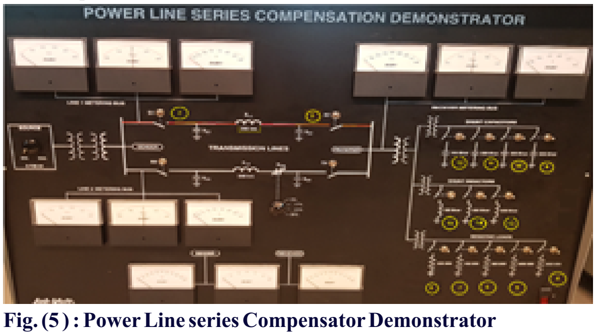



**Fig. (5 ) : Power Line series Compensator Demonstrator**

1.3 Brief information about the lines, metering and load parameters values in this equipment fig. (5):

**Lines:**

1- Line 1 Simulation lengthy 200 km Simulated Nominal Power 4500 MW
2- Line 2 Simulation lengthy 300 km Simulated Nominal Power 3000 MW
3- Compensation 17 %, 25 %, and 34 %

**Front Panel Meters:**

1- Ammeters 0-6000 A (1)
2- Voltmeters 0-1000 kV (2)
3- Phase meter 0-60°
4- Var-meters 0-±2000 (3)
5- Watt-meter 0-5000 MW (2), 0-8000 MW

**Loads values given in table no.(1):**

**Table (1) : The emulated values of varieous types of loads**

| Resistive load | Shunt Capacitors | Shunt Inductors |
|---|---|---|
| R1=(3600MW) | C1=(800MVar) | L1=(600MVar) |
| R2=(1800MW) | C2=(400MVar) | L2=(300MVar) |
| R3=(900MW) | C3=(200MVar) | L3=(150MVar) |
| R4=(450MW) | C4=(100MVar) | |
| R5=(225MW) | | |

The single line diagram used in this paper presented as explained in the fig. (6) where the real power line simulated with the resistive load and acompensation of two components (inductor and capacitor).

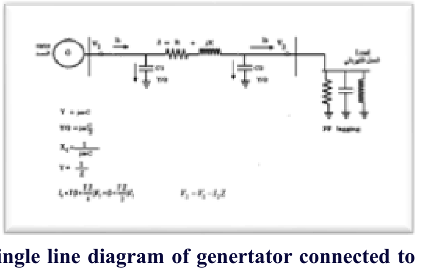


**fig. (6 ) single line diagram of genertator connected to load and compensators**

the expected practical results of current, active power, reactive power, voltages along with power angle and its relation should meet the theoritical equations with a simplicity w

## 1. METHODS:

This paper describes pedagogical methods that have been adopted as a response to these needs and to the desires of both students and lecturers to achieve better learning results. [4]

### 2.1 introduction to method applied in this paper.

The method applied in this paper can be divided into five stages.

1- Understanding the Power Line series Compensator Demonstrator equipment fig. (5).
2- Designing the scenario of executing the experiment in away that help the trainer to understand and memorize the results which was plotted in the line charts and compare the concepts of voltage regulation, load variation and power angle. Furthermore its affection on power stability.
3- Preparing the tables to fill the results of the experiment.
4- Run the experiment by simply switching on main power supply and start execution of the scenario
5- Collecting Data and creating the line chart types to study the cases by using new Microsoft-excel file .
6- Comparing the results with theoretical an measure the feed back of applying this approach of practical training on trainees.

### 2.2 Designing the scenario of execution

The designed steps of operation can be sammarized as follow:

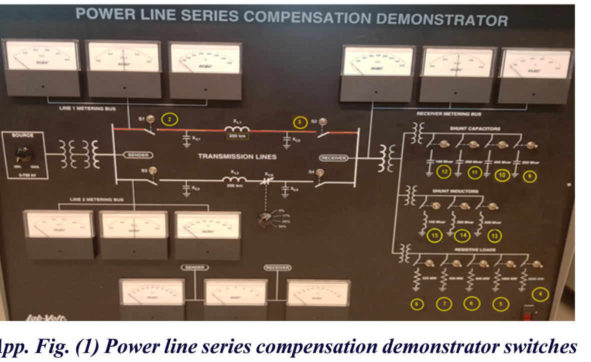
1- Switch ON Power supply and adjust the source voltage to 500KV(emulated voltage). Keep all switches of C.B. (Circuit Breakers) in the open position
2- Close the C.B. of (200Km for case no.1 or 300Km for case no.2 ) transmission line from sending side.
1- Close the C.B. of the selected transmission line from receiving side (without load).
2- In an accumulative way, start adding the resistive loads one by one to the line by closing the switchs. Starting by $R_1$, then $R_2$ till $R_5$.
3- Adding the capacitive compensators (load side) to the full load. Also in an accumulative way, by start adding the $C_1$, then $C_2$ till $C_4$.
4- Adding the inductive compensators (load side) to the full load with the existance of the capacitive compensators. Also in an accumulative way, by start adding the $L_1$, then $L_2$ till $L_3$. see Appedix fig. no.(1) and Appedux tables no. (1-a and 1-b) for full operation steps
5- Record the resultant readings of the meters for every step of increment in the tables, which was created by using Microsoft excel format, for this purpose.

2.3 Running the system accoring to the scenario of execution and recording the data from the meters and create the line types charts necessary for the case study.

2.4 Analysing the resulatant data from the cases of study. The relations among different and variables related to voltage regualtion and power angle , Cases study relations such as:

- Voltage (load side) Vs. cable length and variation of loads.
- Improvement of Power transfer, and power angle
- The effects of Reactive power on power transfer and voltage regulation
- Comparing the results with power transfer equation

***Appendix***




***App. Fig. (1) Power line series compensation demonstrator switches location***

*App. Table no. (1-a): Scenario of operation of switches for step 1to 8 in case (1) 200Km line*

| *Case 1 Source 500KV* | *Load Type* | *Line 1 CB(S) (200Km)* | *Line 1 CB(R) (200Km)* | *Line 2 CB(s) (300Km)* | *Line 2 CB(r) (300Km)* | *Load R1 CB 3600MW* | *Load R2 CB 1800MW* | *Load R3 CB 900MW* | *Load R4 CB 450MW* | *Load R5 CB 225MW* | *Load C1-4 CB* | *Load L1-3 CB* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | no-load | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened |
| 2 | no-load | *Closed* | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened |
| 3 | no-load | *Closed* | *Closed* | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened | Opened |
| 4 | R1 | *Closed* | *Closed* | Opened | Opened | *Closed* | Opened | Opened | Opened | Opened | Opened | Opened |
| 5 | $R_{1,2}$ | *Closed* | *Closed* | Opened | Opened | *Closed* | *Closed* | Opened | Opened | Opened | Opened | Opened |
| 6 | $R_{1,2,3}$ | *Closed* | *Closed* | Opened | Opened | *Closed* | *Closed* | *Closed* | Opened | Opened | Opened | Opened |
| 7 | $R_{1,2,3,4}$ | *Closed* | *Closed* | Opened | Opened | *Closed* | *Closed* | *Closed* | *Closed* | Opened | Opened | Opened |
| 8 | $R_{1-5}$ | *Closed* | *Closed* | Opened | Opened | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | Opened | Opened |

*App. Table no. (1-b): Scenario of operation of switches for step 9 to 15 in case (1) 200Km line.*

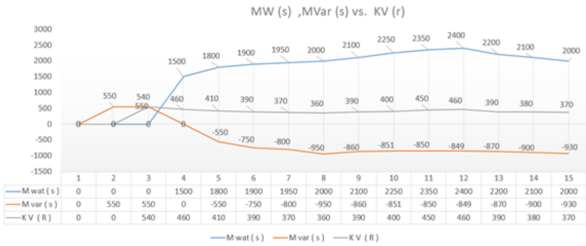
| **Case 1 Source 500KV** | **Load Type** | **Line 1 CB(S) (200Km)** | **Line 1 CB(R) (200Km)** | **Line 2 CB(S) (300Km)** | **Line 2 CB(R) (300Km)** | **Load R1-5 CB** | **Load C1 CB 800MVAR** | **Load C2 CB 400MVAR** | **Load C3 CB 200MVAR** | **Load C4 CB 100MVAR** | **Load L1 CB 600MVAR** | **Load L2 CB 600MVAR** | **Load L3 CB 600MVAR** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **9** | $R_{1-5}C_1$ | *Closed* | *Closed* | **Opened** | **Opened** | **Closed** | **Closed** | **Opened** | **Opened** | **Opened** | **Opened** | **Opened** | **Opened** |
| **10** | $R_{1-5}C_{1,2}$ | *Closed* | *Closed* | **Opened** | **Opened** | **Closed** | **Closed** | *Closed* | **Opened** | **Opened** | **Opened** | **Opened** | **Opened** |
| **11** | $R_{1-5}C_{1,2,3}$ | *Closed* | *Closed* | **Opened** | **Opened** | **Closed** | **Closed** | *Closed* | *Closed* | **Opened** | **Opened** | **Opened** | **Opened** |
| **12** | $R_{1-5}C_{1,2,3,4}$ | *Closed* | *Closed* | **Opened** | **Opened** | **Closed** | **Closed** | *Closed* | *Closed* | *Closed* | **Opened** | **Opened** | **Opened** |
| **13** | $R_{1-5}L_1 C_{1,2,3,4}$ | *Closed* | *Closed* | **Opened** | **Opened** | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | **Opened** | **Opened** |
| **14** | $R_{1-5}L_{1,2} C_{1,2,3,4}$ | *Closed* | *Closed* | **Opened** | **Opened** | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | **Opened** |
| **15** | $R_{1-5}L_{1,2,3} C_{1,2,3,4}$ | *Closed* | *Closed* | **Opened** | **Opened** | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* | *Closed* |

*App, Table no. (2): Recorded values of meters for step 1to 15 in case (1) 200Km line 500KV*

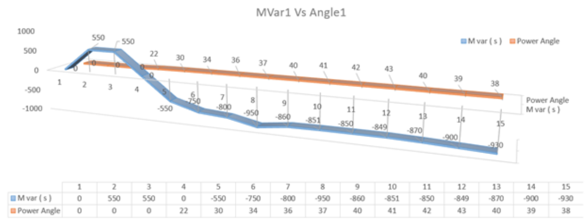
| **Case 1 200Km** | **Sending side** | | | | **Power Angle** | **Receiving side** | | | | **Load Type** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **MW (S)** | **MVar (S)** | **A (S)** | **KV (S)** | | **KV( R )** | **MW (R)** | **MVar (R)** | **A (R)** | |
| **1** | **0** | **0** | **0** | **500** | **0** | **0** | **0** | **0** | **0** | **no-load** |
| **2** | **0** | **550** | **650** | **500** | **0** | **0** | **0** | **0** | **0** | **no-load** |
| **3** | **0** | **550** | **650** | **500** | **0** | *540* | **0** | **0** | **0** | **no-load** |
| **4** | **1500** | **0** | **1750** | **500** | **22** | **460** | **1450** | **0** | **1750** | **R1** |
| **5** | **1800** | **-550** | **2300** | **500** | **30** | **410** | **1700** | **0** | **2300** | $R_{1,2}$ |
| **6** | **1900** | **-750** | **2500** | **500** | **34** | **390** | **1800** | **0** | **2500** | $R_{1,2,3}$ |
| **7** | **1950** | **-800** | **2650** | **500** | **36** | **370** | **1850** | **0** | **2650** | $R_{1,2,3,4}$ |
| **8** | **2000** | **-950** | **2700** | **500** | **37** | **360** | **1900** | **0** | **2700** | $R_{1-5}$ |
| **9** | **2100** | **-860** | **2850** | **500** | **40** | **390** | **2000** | **250** | **2850** | $R_{1-5}C_1$ |
| **10** | **2250** | **-851** | **3000** | **500** | **41** | **400** | **2100** | **350** | **3100** | $R_{1-5}C_{1,2}$ |
| **11** | **2350** | **-850** | **3050** | **500** | **42** | **450** | **2200** | **450** | **3050** | $R_{1-5}C_{1,2,3}$ |
| **12** | **2400** | **-849** | **3200** | **500** | **43** | **460** | **2250** | **470** | **3200** | $R_{1-5}C_{1,2,3,4}$ |
| **13** | **2200** | **-870** | **2900** | **500** | **40** | **390** | **2050** | **250** | **2900** | $R_{1-5} L_1 C_{1,2,3,4}$ |
| **14** | **2100** | **-900** | **2850** | **500** | **39** | **380** | **1950** | **200** | **2850** | $R_{1-5}L_{1,2} C_{1,2,3,4}$ |
| **15** | **2000** | **-930** | **2800** | **500** | **38** | **370** | **1900** | **150** | **2800** | $R_{1-5}L_{1,2,3} C_{1,2,3,4}$ |
| | Power Supply Side | | | | | Load Side | | | | |

*App. Table no. (3): Recorded values of meters for step 1to 15 in case (1) 300Km line 500KV*

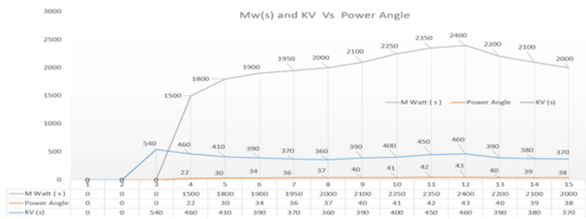
| **Case 2 300Km** | **Sending side** | | | | **Power Angle** | **Receiving** | | | | **Load Type** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **MW (S)** | **MVar (S)** | **A (S)** | **KV (S)** | | **KV (S)** | **MW (R)** | **MVar (R)** | **A (R)** | |
| **1** | **0** | **0** | **0** | **500** | **0** | **0** | **0** | **0** | **0** | **no-load** |
| **2** | **0** | **850** | **750** | **500** | **0** | **0** | **0** | **0** | **0** | **no-load** |
| **3** | **0** | **800** | **800** | **500** | **2** | **600** | **0** | **0** | **0** | **no-load** |
| **4** | **1350** | **-100** | **1150** | **500** | **33** | **439** | **1200** | **0** | **1690** | **R1** |
| **5** | **1520** | **-700** | **1900** | **500** | **43** | **365** | **1300** | **0** | **2100** | $R_{1,2}$ |
| **6** | **1525** | **-850** | **2000** | **500** | **46.5** | **338** | **1320** | **0** | **2300** | $R_{1,2,3}$ |
| **7** | **1550** | **-950** | **2050** | **500** | **48** | **320** | **1322** | **0** | **2330** | $R_{1,2,3,4}$ |
| **8** | **1552** | **-1000** | **2090** | **500** | **49.5** | **318** | **1323** | **0** | **2400** | $R_{1-5}$ |
| **9** | **1700** | **-1020** | **2250** | **500** | **54.5** | **330** | **1450** | **160** | **2500** | $R_{1-5}C_1$ |
| **10** | **1750** | **-1050** | **2350** | **500** | **55** | **340** | **1500** | **250** | **2600** | $R_{1-5}C_{1,2}$ |
| **11** | **1750** | **-1050** | **2350** | **500** | **56** | **340** | **1500** | **265** | **2610** | $R_{1-5}C_{1,2,3}$ |
| **12** | **1800** | **-1055** | **2400** | **500** | **57** | **345** | **1510** | **350** | **2620** | $R_{1-5}C_{1,2,3,4}$ |
| **13** | **1700** | **-1050** | **2250** | **500** | **54** | **330** | **1450** | **200** | **2510** | $R_{1-5} L_1 C_{1,2,3,4}$ |
| **14** | **1650** | **-1020** | **2200** | **500** | **52** | **325** | **1400** | **125** | **2400** | $R_{1-5}L_{1,2} C_{1,2,3,4}$ |
| **15** | **1600** | **-1010** | **2175** | **500** | **51** | **320** | **1350** | **100** | **2350** | $R_{1-5}L_{1,2,3} C_{1,2,3,4}$ |
| | Power Supply Side | | | | | Load Side | | | | |



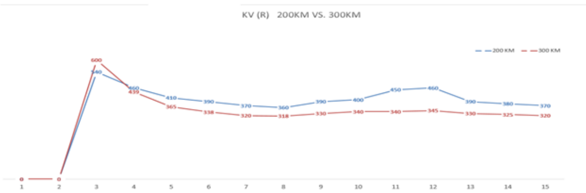

*Appendix Fig.(2): line type chart 200Km Line: MW (s) ,MVar (s) vs. KV (r)*



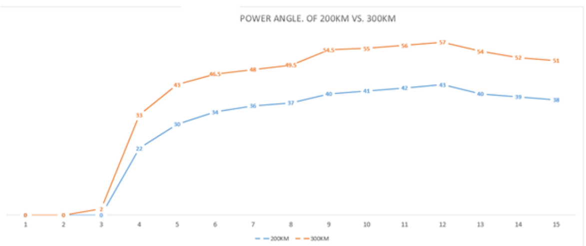

*Appendix Fig.(3): line type chart of 200Km Line: MVar vs. Power Angle*



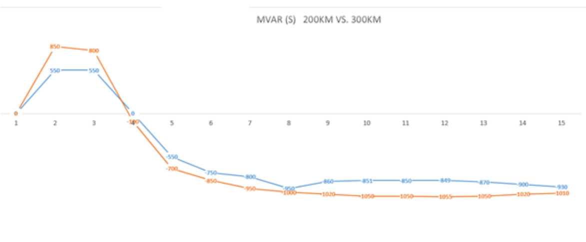

*Appendix Fig.(4): line type chart 200Km Line: Mw(s) , KV vs. Power Angle*




*Appendix Fig.(5): line type chart KV (r) 200KM vs. 300KM*




*Appendix Fig.(6): line type chart Power Angle. of 200KM vs. 300KM*




*Appendix Fig.(7): line type chart MVAR (s) 200KM vs. 300KM*

## REFERENCES

1- Vandhera, S.S. ,(1987).Power System Analysis and Stability: 19.6.1 Steady State Stability of Synchronous Generator Connected to Infinite Bus, Khanna Publishers 2-B NATH MARKET, NAI SARAK DELHI-110006

2- https://www.labvolt.com/solutions/6_electricity_and_new_energy/50-8362-00_power_line_series_compensation_demonstrator

3- IJAR-Indian Journal of Applied Research PRINT ISSN NO 2249 - 555X.Journal DOI : 10.36106/ijar Volume : VIII, Issue : XII, December – 2018 A Hands-On Laboratory Industrial Process Control systems and Advanced Automation Used by DCS. Saad S. Alahmad, Abdelkarim Jamal Ibreik

4- IEEE TRANSACTIONS ON EDUCATION, VOL. 51, NO. 4, NOVEMBER 2008 423 An Alternative Teaching Method for Electrical Engineering Courses Carina Savander-Ranne, Olli-Pekka Lundén