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# Student design projects in King Abdulaziz University for power engineers

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**Abstract** This paper describes samples of practically oriented senior design projects recently incorporated into an undergraduate power systems course at King Abdulaziz University, which have significant positive impact on power engineering education. These projects utilise a personal computer software package that includes transmission line, power flow, short circuit and transient stability computer programs. The senior projects should provide students with a major capstone design experience according to the rules of the engineering accreditation organisation in the USA, the Accreditation Board for Engineering and Technology (ABET). The projects, the way they are utilised and student reaction are all discussed.

**Keywords** personal computers; power engineering education; power system design; software package; student design projects

The engineering accreditation organisation in the USA, the Accreditation Board for Engineering and Technology (ABET) lists the following instructions:

- 1 How to use the computer in engineering problem solving and engineering design as one of the accreditation criteria for undergraduate electrical engineering programs.
- 2 Design projects must be introduced to satisfy the ABET design content in the courses.

The ABET criteria guidelines in section IV.C3.g<sup>1</sup> state, in part, that ‘appropriate computer-based experience must be included in the program of each student. Students must demonstrate a knowledge of the application and use of digital computation techniques for specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work into course work whenever appropriate throughout the academic program’. The guidelines further state that ‘appropriate use of computers must be integrated into courses and laboratories throughout the program. The program must include instruction in software design using modern programming techniques, structured programming in a high-level language, and experience in the use of at least one operating system. Students must be taught to use software for analysis, design, and simulation of engineering problems’.

The Electrical Engineering and Computer Engineering Department at King Abdulaziz University, as with any institution that offers an undergraduate electrical engineering program, is committed to fulfilling the ABET accreditation requirements

by providing all of its students within the department with easy access to substantial resources in computer hardware and software, and proper training in the use of computers for analysis, simulation, and design in electrical engineering problems. The meaning of Engineering Design (ED), as quoted from ABET, is ‘engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, an engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design component of a curriculum must include some of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact. Courses that contain engineering design normally are taught at the upper division level of the engineering program. Some portion of this requirement must be satisfied by at least one course, which is primarily design, preferably at the senior level, and draws upon coursework in the relevant disciplines.

The purpose of this paper is to present and discuss the senior design projects scheduled by the author in the power and machines program.

### **Power and machines program**

The Electrical Engineering and Computer Engineering Department at King Abdulaziz University has four programs:<sup>2</sup>

- 1 Power and machines;
- 2 Computer;
- 3 Electronics and Communications; and
- 4 Biomedical.

The Power and Machines group offers 16 undergraduate courses in the power systems area. They are listed below:

#### **Compulsory Courses**

1	Electromechanical energy conversion I	EE341
2	Electrical power system I	EE351
3	Electromechanical energy conversion II	EE441
4	Power electronics	EE442
5	Electrical power system II	EE451
6	High voltage technique I	EE452
7	Power transmission and distribution	EE453
8	Switchgear and protection of power systems	EE454

### Elective Courses

1	Electrical measurements	EE303
2	Electromechanical energy conversion III	EE443
3	Economic operation of power systems	EE455
4	High voltage technique II	EE456
5	Utilisation of electrical energy	EE457
6	Computer applications in power systems	EE458
7	Special topics in electrical engineering	EE498

### Senior Projects

EE499

Each of the power courses has a term design project. The senior project is a two-term design project and must be registered by every student during the last two terms before graduation. These design projects have been introduced not only to satisfy the ABET design content in the courses, but also because they have proven to be excellent vehicles for teaching the subject and for motivating students to go into the power systems field. The project emphasises practical applications in power system design and requires computer utilisation. The idea is to introduce a design project which is similar to an actual problem confronted by engineers in the power industry. This objective pulls together all of the theory learned in class. It also teaches students to exercise engineering judgement and apply it to a practical problem.<sup>3</sup>

It has also been found that the design projects provide a good way to review basic power systems theory and provide an excellent opportunity to train engineers in real world situations. The power industry has hired new graduates only to find that they know basic theory but not practical applications. Our program is organised to provide application experience as well as theory.

Companies that hire BSc degree electrical engineers with no practical experience spend a substantial amount of time and money in training these engineers before they are able to participate productively in the company. Frequently, senior engineers within a particular department do not have the time or training to give all the necessary information and background for a specific problem. The young inexperienced engineer hesitates to ask necessary but seemingly trivial questions. The consequences of this are poor production, loss of time and money, and inadequate results. The design projects have helped in closing the gap between the academic and working environments.

### Undergraduate computer facilities

At King Abdulaziz University, Faculty of Engineering, all entering engineering freshmen are required to take a one-year, two-semester class in engineering analysis and problem solving. During the one-year course span, working knowledge of a computer language, the use of Microsoft Office, and the use of computer functions to perform mathematical analysis are introduced. The students are required to use the computer to compose many of their written reports. Computer laboratories equipped with IBM compatible PCs are open to all entering engineering freshmen.

Additional computer laboratories equipped with IBM and IBM compatible personal computers are situated in the electrical engineering and computer engineering departmental computer lab, the university library, and the university computer center. The spreadsheet programs, Lotus 123, Quatro Pro, and Excel, and the word-processing software are the basic software installed on the desk top personal computers. In addition, mathematical packages such as Mathematica, MATLAB, and Mathcad are also provided on many of the computers for solving mathematical problems.

### **Power system design projects**

Many ABET-recognised programs have three or four courses directly addressing engineering design and various levels with a capstone design course at the senior level. The EE499 senior project course will provide students with a major capstone design experience, to include:

- 1 In-depth design work on a practical engineering problem at a technical level similar to that encountered in industry;
- 2 Technical content drawn from multiple areas of the electrical engineering curriculum;
- 3 Experience in planning and managing projects; and
- 4 Further experience in documenting and communicating engineering work.

This section presents some of the senior design projects scheduled by the author in the power and machines program.

#### **Electrification of an industrial area<sup>4</sup>**

In this project, it is required to supply electricity to a new industrial area. This area contains residential buildings, schools, hospital, mosque, gardens and six factories as shown in Figure 1. Project steps are:

- 1 Indoor lighting design for all buildings (factories, houses, . . . etc.).
- 2 Outdoor lighting design (streets, fences, stadium, gardens, . . . etc.).
- 3 Design the power supply for each factory to energise the machines.
- 4 Design of single phase c.s.a. for all different loads.
- 5 Design the rating of each CB and fuse for static and dynamic loads.
- 6 Design the single line diagram for each building taking into account the idea of balanced load over the three phases.
- 7 Design of the main three phase 380V feeder from the point of view of c.s.a and routes in the industrial area.
- 8 Design the locations and ratings of transformers 11/0.4kV, including the ring system connecting them, and the main transformer 132/11 kV.
- 9 Design of different earthing systems for factories that have different earth resistivity.
- 10 Design of capacitor ratings required for power factor improvements of each factory. Economic considerations of cost and saving must be calculated.

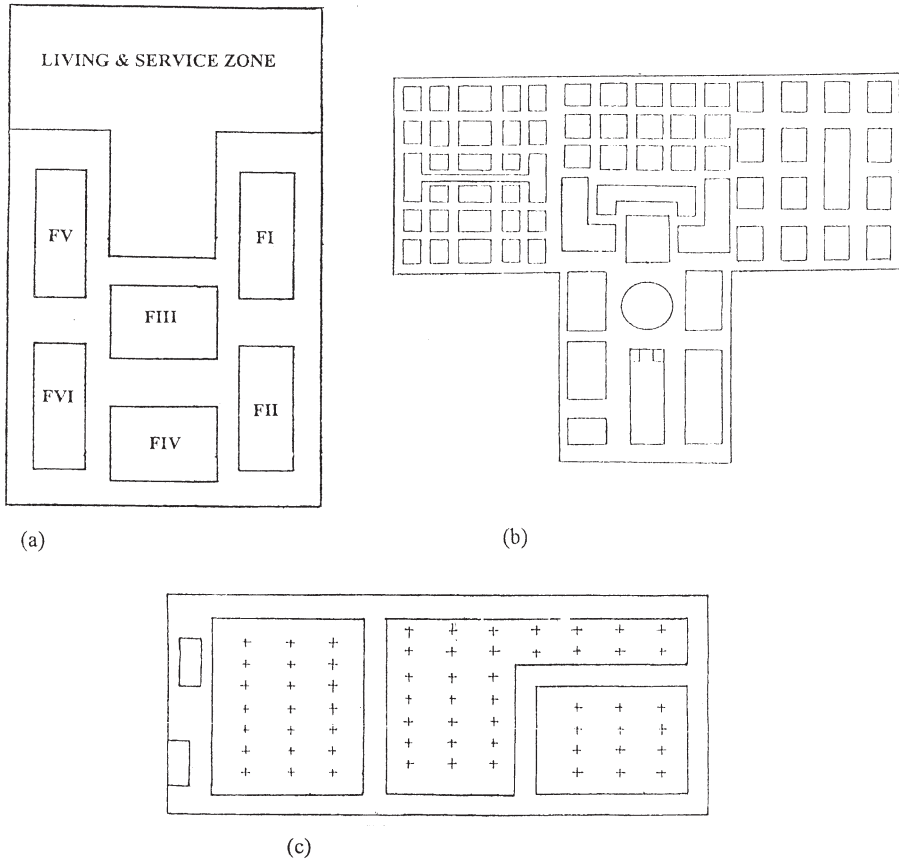


Fig. 1 Details layout of the industrial area. (a) Layout of the industrial area; (b) Living and service zone; (c) Factory FI with machines layout.

- 11 Preparing the bill of quantity for the material of the project including numbers, weights and lengths.

### Optimum design of SVC parameters and locations for improvement of power system performance<sup>5</sup>

The reliability and modest installation costs of solid state equipment makes SVC an attractive means of high-speed VAR control over the other shunt compensating equipment. Figure 2 shows the schematic layout of FC + TCR. The project is set up using the Ward and Hale system, Fig. 3, and can be outlined as follows:

- 1 Primary investigation of the system using load flow program.
- 2 Design the location of SVCs according to certain criteria.
- 3 Design the parameters of SVCs (L and C) to improve the performance of the

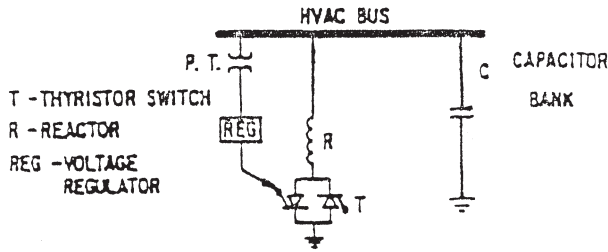


Fig. 2 Schematic layout of FC + TCR.

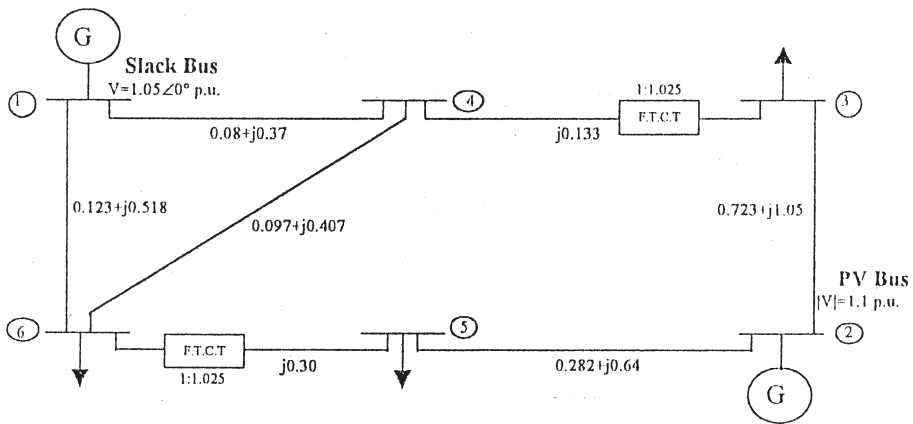


Fig. 3 6-Bus Ward and Hale system.

power system during overloads, lightloads, line outages, load rejection, transformer outages, and PV-bus emergencies.

- 4 Design the initial firing angles of SVC.

### Residential applications of PV (photovoltaic) power system design and economic aspects

In the last decade a growing interest in renewable energy source applications has been observed. Alternative energy sources like wind, photovoltaic, and geothermal have several advantages over non-renewable ones, i.e. coal, oil, and gas. They are non-polluting, modular, and free. Many applications in photovoltaic energy utilisation have been developed. They include water pumping, lighting, communications, refrigeration and vaccine storage, etc. Systems based on the use of photovoltaics can be economically attractive for power supply in remote areas.

The generation of electricity by a photovoltaic module is a function of many factors. Due to the stochastic nature of solar radiation, photovoltaic generator design, as opposed to conventional generation system design, should be based on the

probabilistic approach, which is used to evaluate the performance and electricity generation of the PV module.

The major uses of residential PV systems are stand-alone for remote applications and interconnected with an electric utility to feed residential loads. Two modes of operating a stand-alone PV system can be used. In the first mode, the load is supplied by the PV system through the sunshine hour, while the load is fed from a storage battery, SB, charge from this system, through the other hours of the day (Fig. 4(a)). In the other mode of operation, the load is fed by a storage battery charged from the PV system (Fig. 4(b)). The residential utility–interactive PV power system shows promise of widespread application as an alternative energy source in the near future. These systems are connected to the utility feeder through bi-directional kilowatt hour meters, which records the energy flow in each direction (Fig. 5).

Design of a PV power system for residential applications can be divided into:

- 1 The electric load of the residence.
- 2 Solar radiation system.
- 3 Photovoltaic system.

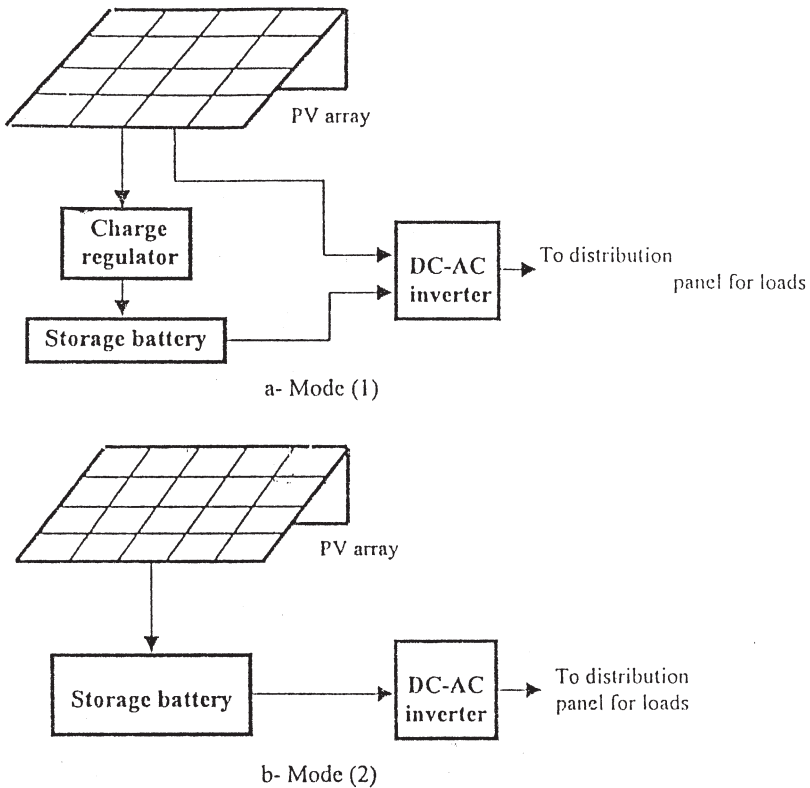


Fig. 4 Proposed operation modes of a stand-alone residential PV system.

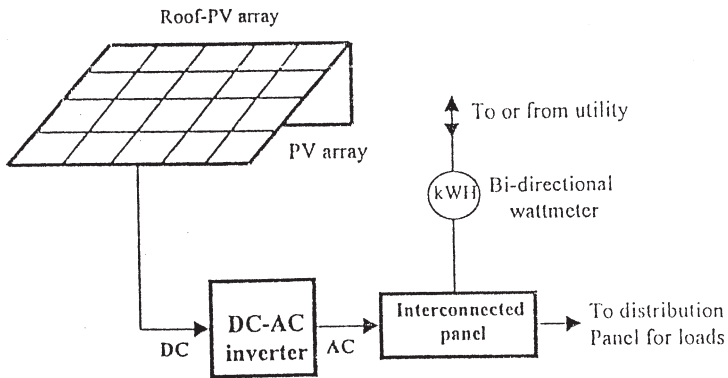


Fig. 5 Diagram of residential PV system-interactive utility.

### *The electric load of the residence*

The residential load features show the daily load curve of a house through the different seasons of the year. These features may be occupants, number of workers, cooking and air conditioning. The devices used in a residence also affect this load curve. These devices are lighting, refrigeration, television, automatic washing machine, air-conditioning and electric heating. The residential load can be monitored when designing a residential PV system.

### *Solar radiation system*

Solar radiation can be expressed in hourly mean values of global solar radiation. The available data are the daily mean values of the chosen site for different successive years. The isolation model required for computation of the solar radiation on a PV array depends on the method of operating the residential PV system. These methods are a fixed or tracking PV system. A tracking PV array increases solar radiation and the corresponding energy generate more than the fixed method.<sup>6,7</sup>

### *Photovoltaic system*

The PV system can be divided into the following:

*The solar generator system:* The solar generator area is a function of the site, the residential load at this site, the efficiency of the PV generator used, the degree of correlation between the residential load and the solar radiation at this site and the reliability base required of the system. The reliability base of the system in this project will be expressed in terms of loss of load probability. The solar cells of the PV generator can be mounted on the tiled ceiling of the residence under which its accessories can be erected.

*The battery storage system:* The size of the battery used to feed the electric load of the residence during the solar radiation off period depends mainly on the overall efficiency of the battery and the reliability of the system.

*The harmony between PV and battery storage systems:* The service time of both PV system and battery storage system is very important in determining the sizes of both systems. The fact that solar radiation and consequently the electrical power output of the PV system near sunrise and sunset is low means that the battery must share the PV system to feed the load in these periods.

*Economic aspects of a stand-alone residential PV system*

The economy of a residential PV system can be developed from annual energy output, capital and operation costs. These parameters are dependent on the design of PV system to accommodate the mode and method of operating this system at the considered site. The capital cost associated with the constitution of PV system is covering all materials for installation and wiring the PV array, power conditioner and storage battery costs. PV array cost and array installation cost can be expressed as a function of number of modules or peak power of PV system. The storage battery capacity and its cost are dependent on the method of operating stand-alone residential PV system.

Power flow/symmetrical short circuit/breaker-fuse selection<sup>8</sup>

The 26-bus power system network of an electric utility is shown in Fig. 6 using data from Ref. [9]. The student must do the following assignments:

- 1 Run the power flow program during heavy and light loads.
- 2 Suggest one method of increasing the voltage magnitude at each bus  $0.99 \leq V \leq 1.0$  p.u. during both light and heavy loads, using any voltage control method including use of generator excitation control, tap changing and regulating transformers, static capacitors, static VAR systems and parallel transmission lines.
- 3 Using the symmetrical short circuit program, compute the subtransient fault currents for a bolted three-phase-to-ground fault at all buses. For synchronous machines, use subtransient reactance. Also, compute bus voltages during the faults and the positive sequence bus impedance matrix.
- 4 Using zero-, positive-, and negative reactances and subtransient machine reactances, compute the subtransient fault currents for (1) single line to ground, (2) line to line and (3) double line to ground bolted fault at each bus. Also compute the zero-, positive-, and negative-sequence bus impedance matrices.
- 5 Select a suitable circuit breaker from Ref. [10] for sending and receiving end of each transmission line and high-tension side of each transformer. Each breaker that the student selects should: (1) have a rated voltage larger than the maximum system operating voltage; (2) have a rated continuous current at least 30% larger than normal load current; and (3) have a rated short circuit current larger than the maximum fault current for any type of fault at the bus where the breaker is located. This conservative practice of selecting a breaker to interrupt the entire fault current, not just the contribution to the fault through the breaker, allows for future increase in fault currents.

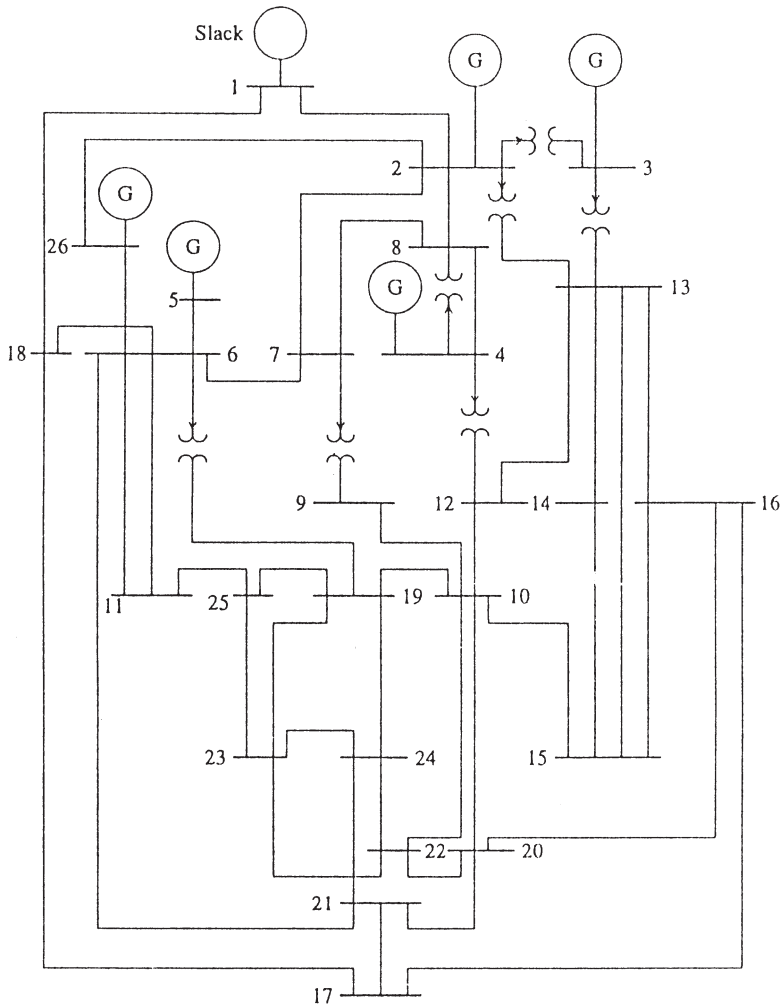


Fig. 6 One-line diagram for the studied network.

### Transmission line design<sup>8</sup>

Design a three-phase 60 Hz, 75 km length, transmission line rated continuously to transfer 1000 MVA and 100  $\Omega$ -m earth resistivity. Specifically, the student must provide:

- 1 A detailed sketch showing placement of phase conductors and shield wire(s), their height above ground both at towers and at the point of maximum sag between towers, the average span, and the right-of-way required.
- 2 A description of the composition and construction of phase conductors and shield wire(s).

- 3 The following transmission line electrical parameters:
  - rated voltage (kV)
  - rated current (A)
  - series sequence impedance matrix ( $\Omega/\text{km}$ )
  - shunt sequence admittance matrix ( $\text{S}/\text{km}$ )
  - conductor surface electric field strength (kV/cm)
  - lateral profile of ground-level electric field strength (kV/m)
- 4 A one-page typed description (with decent prose, good grammar, and correct spelling) of the advantages and disadvantages of his or her design. Student discussion should include technical factors (such as line losses, electric field strengths, clearance, etc.) and economic factors (including capital cost of installation and operating cost).

A second transmission line design project is the same as the first project described above, except that:

- 1 The line must be a double-circuit line;
- 2 Phase conductors must be bundled;
- 3 Design and discussion must include corona considerations.

A third transmission line design project is a line design for the following three line lengths: 75, 200 and 500km, assuming steady state, positive-sequence operation. For each length, the student must determine:

- 1 ABCD parameters (with no line compensation).
- 2 Equivalent  $\Pi$  circuit series impedance ( $\Omega$ ) and shunt admittance (S) (with no compensation).
- 3 The total amount of shunt reactive compensation (%) required to achieve 10% voltage regulation for this line (full load is 1000MVA at unity power factor). One-third of the total compensation is to be placed at the sending end, at the centre, and at the receiving end of the line. Shunt compensation is removed at heavy loadings.
- 4 ABCD parameters and equivalent  $\Pi$  circuit for the shunt compensated line.
- 5 Maximum theoretical power (MW) that the line can transfer at rated sending- and receiving-end voltages.
- 6 Practical line loadability (MW) based on a voltage drop limit  $V_R/V_S \geq 0.95$  and  $35^\circ$  maximum angular displacement across the line.

### Planning project<sup>8</sup>

Figure 7 shows a single-line diagram of four interconnected power systems identified by different graphic bus designations. The following data are given:

- 1 There are 31 buses, 21 lines, and 13 transformers.
- 2 Generation is present at buses 1, 16, 17, 22 and 23.
- 3 Total load of the four systems is 400MW.
- 4 Bus 1 is the swing bus.
- 5 The system base is 100MVA.

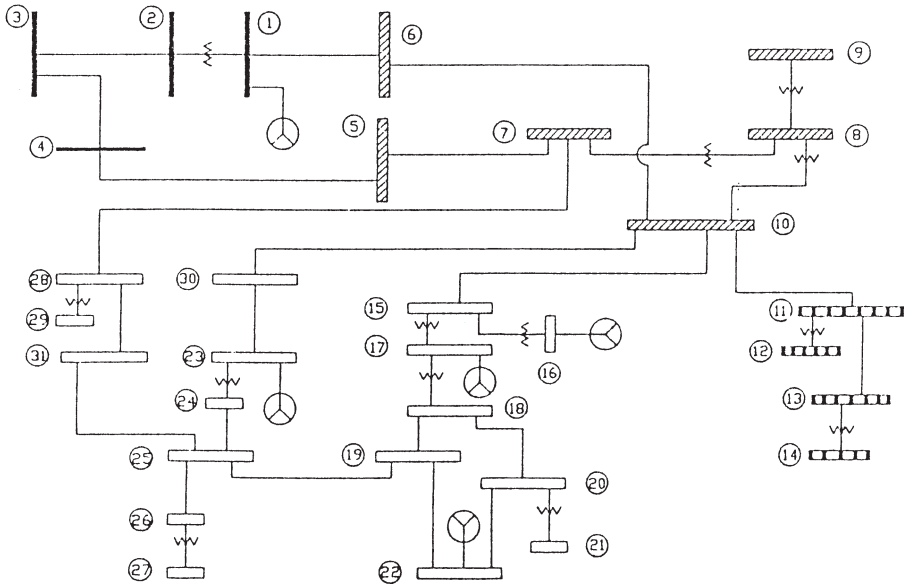


Fig. 7 Planning project single-line diagram: 31-bus interconnected power system.

- 6 Additional information on transformers and transmission lines is provided in Refs [11,12].

Based on the data given, the student must do the following:

- 1 Allocate the total 400MW system load among the four systems.
- 2 For each system, allocate the load to buses that you want to represent as load buses. Select reasonable load power factors.
- 3 Taking into consideration the load allocated above, select appropriate transmission line voltage ratings, MVA ratings, and distances necessary to supply these loads. Then determine per-unit transmission line impedances for the lines shown on the single-line diagram (show calculations).
- 4 Also select appropriate transformer voltage and MVA ratings, and determine per-unit transformer leakage impedances for the transformers shown on the single-line diagram.
- 5 Develop a generation schedule for the 5 generator buses.
- 6 Show on a copy of the single-line diagram per unit: line impedances, transformer impedances, generator outputs and loads selected above.
- 7 Using the power flow program, run a base case power flow and show on the single-line diagram per unit bus voltages as well as real and reactive line flows, generator outputs, and loads. Flag any high/low bus voltages for which  $0.95 \leq V \leq 1.05$  per unit and any line or transformer flows that exceed normal ratings.
- 8 Provide a typed summary of results along with the above calculations, power flow provided, and copies of the single-line diagram.

## Others

Other senior projects can be titled as:

- (1) Transient stability project.
- (2) Objective function design for reactive power dispatch.<sup>13</sup>
- (3) Design of a device for on-line fault level measurements.<sup>14</sup>
- (4) Design of load-frequency control system.<sup>15</sup>

## Project evaluation

The project is evaluated from all perspectives. The overall quality of the report is of great concern. Engineers are often criticised for their poor communications skills. Very often students are evaluated purely on achieving the correct answer and not on the overall presentation of the results. This is a mistake, as any practising engineer can testify. Communication skills are very important in the real world. It is necessary not only to reach the correct solution but also to be able to communicate it clearly to those concerned. The solution must include all background information, data, and calculations. A summary sheet following a special format must also accompany the report.

## Conclusions

Students in KAAU's engineering programs appear to benefit from and even enjoy working with computers. Much of the complicated work in analysis, simulation and design which previously had to be done manually can now be performed easily and quickly by using a computer. The improved efficiency from proper use of computers has done much to alleviate students' frustration and to give students an early sense of satisfaction and accomplishment. This, in turn, further stimulates students' interest in incorporating the use of computers in their engineering curriculum.

The design projects presented in this paper are added to the curriculum to prepare students for their future work as well as grounding them in theory. It has achieved this goal and it has proven to be a valuable tool in the teaching of power systems.

The availability of the power system analysis and design software package has extended classroom capabilities and enhanced student interest in power engineering courses. The reaction of students to the software has been positive. The software package has allowed them to work on more different and realistic problems and make it an innovative tool in the learning process. The result for the industry is that they have a broader field from which to select candidates. Also those doing the interviewing have commented about the quality of the candidate and also have reported very favourably about employees trained by the new approach.<sup>16</sup>

The use of design projects has generated many positive results. Student reaction to the project has been very good and interest has been increased. The quality of graduates improved. Industry is receiving engineers trained in solving real world problems. Also the body of research and literature is growing and will be used as a base for future research and problem solving.

## References

- 1 *Criteria for Accrediting Programs in Engineering in The United States, Effective for Evaluation During 1993–1994 Accreditation Cycle* (Engineering Accreditation Commission, Accreditation Board for Engineering and Technology, N.Y., 1993).
- 2 King Abdulaziz University, *Faculty of Engineering Bulletin* (2000).
- 3 Ramon Betancourt and William W. Torre, 'The use of a design project as an innovative and practical approach to the teaching of power systems', *IEEE Trans. Power Systems*, **4**(1) (1989), 372–379.
- 4 'Electrification of an industrial area', BSc Project, Spring 1421 H–2000 G.
- 5 'Optimum design of SVC's parameters and locations for improvement of power system performance', BSc Project, Spring 1422 H–2001 G.
- 6 S. A. Klein, 'Calculation of monthly average insolation on tiled surfaces', *Solar Energy*, **19** (1977), 325–329.
- 7 K. Kalaitzakis and G. S. Stavrakakis, 'Size optimization of a PV system installed close to sun obstacles', *Solar Energy*, **57**(4) (1996), 291–299.
- 8 J. D. Glover and L. F. Dow, 'Student design projects in power engineering', *IEEE Trans. Power System*, **5**(4) (1990), 1390–1399.
- 9 H. Saadat, *Power system analysis* (McGraw Hill, New York, 1999).
- 10 *Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, ANSI C37.010* (New York: American National Standards Institute, 1972).
- 11 Westinghouse Electric Corporation, *Transmission and Distribution Reference Book*, 4th edn (Westinghouse, Pittsburgh, 1964).
- 12 Aluminum Association, *The Aluminum Electrical Conductor Handbook*, (Aluminum Association, Washington DC, 1971).
- 13 'Design of a new objective function for reactive power dispatch', BSc Project, Spring 1424 H–2003 G.
- 14 'Design of a device for on-line fault level measurements', BSc Project, Spring 1423 H–2002 G.
- 15 'Design of load-frequency control system', BSc Project, Spring 1424 H–2003 G.
- 16 K. Pyko and G. Zorpette, 'Can power engineering education be reenergized?' *IEEE Spectrum*, (Dec. 1986), 30.