FRAMEWORK FOR OPERATIONS RESEARCH INSTRUCTION FOR FUTURE ELECTRIC POWER ENGINEERS

Edwin B. Cano
Graduate School of Engineering

Dhon G. Dungca
Department of Industrial Engineering

Holy Angel University

ABSTRACT

Philippine electric power industry has put a new face in itself: deregulation. With its new structure, optimization of planning and operations of electric power systems will be vital. Optimal performance of the power network will be highly considered may it be economics and/or technical. This paper presents a framework for Operations Research (OR) instruction for future engineers of electric power systems. The key to optimized electric network in the coming years is to educate and train electrical engineering students solve power system problems utilizing OR. The manuscript is comprised of appropriate OR solutions to power system problems. The presentation will be useful for teachers giving OR courses to students of electrical engineering.

I. INTRODUCTION

The restructuring of electric power industry is made possible by R.A. 9136 [1]. The former vertical structure of planning, operations of electric power system in the country will be subject to competition in the area of generation and continuous regulation for transmission and distribution business. Electric energy and reserves will be traded in Wholesale Electricity Spot Market (WESM) [5] which will entail bidding and buying strategies among industry participants. This is where competition comes in. With regulation, the Energy Regulatory Commission (ERC), an agency created by R. A. 9136, will continue to oversee planning and operations of transmission and distribution owners. The Philippine Grid Code (PGC) [3] and the Philippine Distribution Code (PDC) [4], governs the planning and operations of both regulated power areas. In [3], [4] and [5], optimization techniques are essential methods to electric power industry players in order for them to actively participate in the deregulated set- up.

The transmission grid operator and owner needs operations research (OR) for maintenance scheduling and management of electric power assets, system reliability and power delivery [3]. The necessary optimization will be due to regulated status of the transmission area.

For power distribution business, distribution planning requires optimization techniques as stated in [4]. Location and sizing of distribution power substation will be necessarily optimized. The routing and controlled switching of distribution feeders will also be optimally determined. The optimization [4] of reactive power compensation for voltage regulation and minimization of system losses will be likewise called for.

At the WESM, a market dispatch optimization model [5] will be used for determining generation dispatch targets, reserve allocations, associated energy prices at all trading nodes and reserve prices where applicable. For generation companies, optimal bidding strategies will be vital for their participation in the WESM. Further, optimized investment portfolio for electric power generation will take its place in the effective risk evaluation of such projects.

In the Technical Panel for Engineering, Architecture and Maritime Education for Electrical Engineering (TPEAME-EE) [2], OR is included in the course electives for Electrical Engineering (EE) students. The subject, if offered or enrolled by the student, follows an outline like of those given to Industrial Engineering (IE) students. With this, EE students learn techniques of OR as applied to production and manufacturing systems which should not be the case since OR is an indispensable tool for future electric power system engineers in the deregulated era of Philippine electricity industry. There is a need to set-up a necessary framework for OR instruction to EE students.

This paper presents an outline for an OR course provided for EE students and is organized as follows. Section II provides the overall picture for the framework and imparts OR techniques and applications to electric power systems. Section III gives the discussion and analysis for the proposed framework. The conclusion and recommendation are presented in Section IV.

II. Operations Research Instruction for EE Students

A. Course Framework

The required structure for the coursework is in the light of the needs of the electricity industry. TPEAME-EE [2] suggests the discussion of Linear Programming (LP), Integer Programming (IP) and Dynamic Programming (DP). The subject revolves around these techniques since most of power system problems can be solved using the said methods. Also, bearing in mind a one-semester coursework, the designed framework should satisfy time constraint yet includes the important theory and applications needed to be learned by the students. Figure 1, below, presents the course outline towards effective OR instruction for EE students.

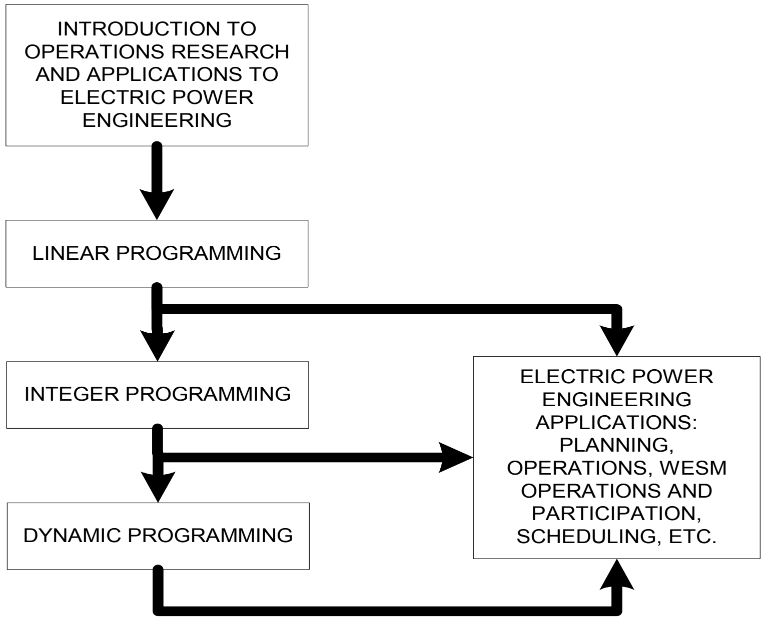

FIGURE 1. Framework for OR Instruction for Electrical Engineering students.

The subject can be divided in the following: for Preliminary period, discussion of LP and applications; for Middle term, discussion of IP and applications; and for Finals term, DP and applications. The following subsections presents LP, IP and DP theory and applications appropriate for the area under discussion.

B. Linear Programming and Applications

LP is a powerful technique for dealing with the problem of allocating limited/scarce resources among competing activities as well as problems having similar mathematical formulation. It has been ranked among the most important scientific advances of the mid-20th century and its impact has been extraordinary. Precisely, it is a standard tool that addresses the problems of most companies, businesses and some industries around the world.

LP uses a mathematical model to describe the problem of concern. From the word “linear”, it is understood that the mathematical functions in this model are linear functions. The word “programming” on the other hand is synonymous to the word “planning”. Thus, LP involves the planning of activities to obtain an optimal result, that is, the best alternative amongst all feasible alternatives.

In solving a problem, an analyst must use the general LP model. Gathering data and fitting this information in the general LP model will formulate the model. Certain symbols are commonly used to denote the various components of a LP model.

Z = value of the overall measure of performance
x_j = level of activity j (for j = 1,2,…,n)
c_j = increase in Z that would result from each unit increase in level of activity j.
b_i = amount of resource i that is available for allocation to activities (for i= 1,2,…,n)
a_{ij} = amount of resource i consumed by each unit of activity j.

x1, x2, …, xn are called decision variables

The values of cj, bi, and aij (for i= 1,2,…,m and j = 1, 2, …, n) are the input constants or the parameters of the model.

The model to select the values for x1, x2, …, xn so as to

Maximize $\quad Z = c1x1 + c2x2 + \dots + cnxn$

Subject to the restrictions

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \le b_1$$
$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \le b_2$$

$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \le b_m$$

$$x_1 \ge 0,\ x_2 \ge 0,\ \dots\ x_n \ge 0$$

LP applications to electric power engineering include power system planning [6] [7], fuel scheduling [8], overcurrent protection coordination [9]. Perhaps the most important application of LP to power systems is optimal power flow [8]. Below is a simple generation planning in LP model, taken from [7], where the problem is to minimize the total cost of meeting the demands at all times in all future years, where future costs are discounted at a rate $\propto$, so the effective cost of P 1.00 spent in a year is

$$\frac{1}{(1 + \propto)^t} \qquad (1)$$

The LP model is to minimize

$$\sum_s \sum_t \Big(\sum_{t1=t}^{T} [\ 1/\ (1 + \propto)^t]\Big)\ (\propto C_{CAPs} + C_{Fs})\ y_{st} + \sum_s \sum_t \sum_l [\ 1/\ (1 + \propto)^t]\ F_l\ C_{vs}\ x_{lst} \qquad (2)$$

subject to

$$x_{lst} - \sum_{t1=t}^{T} y_{lst} \leq Q_{Os} \quad \text{(for all l, s, t)} \qquad (3)$$

$$\sum_{t} x_{lst} = D_{lt} \quad \text{(for all l, t)} \qquad (4)$$

where:

Subscripts:

l	Demand level (=1 for the lowest level in year =L for the highest level in year)
s	Source (i.e. generator)
t	Time period (year)

Constants:

C_{CAPs}	Capital cost per unit of additional capacity (incurred in year before commissioning) (P/W)
C_{Fs}	Fixed annual cost for maintaining a unit of capacity (P/W)
C_{Vs}	Variable cost of using generator (P/W-year)
D_{lt}	Demand (MW)
F_l	Fraction of year for which demand is at level l
Q_{Os}	Initial capacity of source (MW)
$\propto$	Discount factor

Variables:

X_{lst}	Amount of capacity used from source s when the demand is t level l in time period t (MW)
y_{lst}	Amount of new capacity installed (MW)

In this formulation, the capital costs are not paid as such. Instead the money is considered to be borrowed, and an interest is paid annually, at a rate $\propto$. This implicitly values the capital assets at the end of time horizon cost, which is without any depreciation.

The limitation of LP to power system problems is that most parameters in power system are non-linear. Linearization of variables is needed and therefore the LP solution can be considered approximation of the true solution. Table 1 provides summary of some LP models and applications to electric power engineering.

Area of Applications	Objective Function	Constraints
Planning/Operations	Minimize construction investment in power network planning [6] [7]	1. Voltage Limitations ($\pm$5%) 2. Equipment Loading Limitations (<90%) 3. Capacity equals Demand +Losses
Planning/Operations	Minimize system losses	
	Optimal Power Flow[8]	
Design/System Protection	Optimal Overcurrent Protection Coordination [9]	1. Time Dial Setting of Primary Relay Protection 2. Time Dial Setting of Back Up Relay Protection 3. Operating times of Primary and Back Up Relays
Operations/Fuel Scheduling	Minimize operating cost [8]	1. Delivered Fuel equals scheduled load 2. Delivered Fuel equals required fuel for operations

TABLE 1. Summary of some Linear Programming applications in electric power engineering.

C. Integer Programming and Applications

Integer programming (IP) is similar to LP except that integer programming problems require decision variables to have integer values. Decision variables only make sense when they have integer values in some practical cases. So the mathematical model for integer programming is the linear programming model with the one additional restriction that the variables must have integer values. This is true in activities such as assigning people, machines and vehicles.

In such cases where the problem only requires some of the variables to have integer values, the model is referred to as Mixed Integer Programming (MIP). Another area of IP application is the solving of problems involving a number of interrelated “yes-or-no decisions.” Thus, decision variables (binary decision variables) are restricted to just two values, 0 and 1. IP problems that contain only binary variables are called Binary Integer Programming (BIP).

IP problems are much more difficult to solve than LP problems. The Simplex Method, which is used in solving LP problems, can be used for IP problems by simply rounding the non-integer values to integers in the resulting solution. However, the solution may no longer be feasible after it is rounded. Also, there is no guarantee that this rounded solution will be the optimal integer solution. That is why some kind of enumeration procedure for finding an optimal solution is considered. This is called the Branch-and-Bound Technique.

The nature of power systems being integer in case of number and allocation of equipment makes IP friendlier to electric power engineering. Electric energy and reserves auction, Generation Company bidding strategies and unit commitment of generators [10] problems are provided solutions using IP. Distribution system allocation and number of reactive power compensation devices, substation location, location and number of voltage regulation equipment are determined using the same OR method. An example of IP solution to phase balancing in electric power distribution systems [11] is illustrated below. Phase balancing problem is to make a feeder system balanced in terms of phases. A balanced system has smaller worst voltage drops and energy losses [11].

Minimize U_j

subject to

$$\max\{|I_{j,a} - I_{j,c}|, |I_{j,b} - I_{j,c}|, |I_{j,a} - I_{j,b}|\} = U_j \qquad (5)$$

$$I_{j,\phi} = \sum_k I_{k,\phi} + \pi^i_{\phi,1} \bullet d_{i,1} + \pi^i_{\phi,2} \bullet d_{i,2} + \pi^i_{\phi,3} \bullet d_{i,3} \qquad (6)$$

$$\pi^i_{\phi,1} + \pi^i_{\phi,2} + \pi^i_{\phi,3} = 1 \qquad \text{for all } \phi = a, b, c \qquad (7)$$

$$\pi^i_{a,\omega} + \pi^i_{b,\omega} + \pi^i_{c,\omega} = 1 \qquad \text{for all } \omega = 1, 2, 3 \qquad (8)$$

$$I_{j,\phi} \le C_j \qquad (9)$$

$$\pi^i_{\phi,\omega} \in \{0, 1\} \qquad \text{for all } i \qquad (10)$$

where

j	is any monitored branch
U_j	is the unbalanced flow on branch j
$I_{j,\phi}$	is the ϕ phase flow on branch j
$\pi^i_{\phi,\omega}$	is the decision variable for ωth load tapping to phase ϕ at node i
C_j	is the phase line capacity of branch j

Table 2 provides a synopsis of some IP solutions to power system problems.

Area of Applications	Objective Function	Constraints
Electricity Market Auction and Bidding Strategies [10]	Maximize profit	1. Generator capacity limits 2.Reserves limitations 3. Network constraints 4. Operation costs
System Operations	Minimize operation costs (unit commitment) [10]	1. Generator capacity limits 2.Reserves limitations 3.Ramp rate limits
Distribution system operations planning	Minimize system losses/ operations costs [11] [12]	1.Voltage limits (±5%) 2.Loading limits of distribution equipment 3.Harmonic limits

TABLE 2. Summary of some Integer Programming applications in electric power engineering.

D. Dynamic Programming and Applications

Dynamic Programming is a multistage problem solving wherein decisions are broken up into smaller components or parts. And then, the previous decisions are recombined in some form or another to obtain the desired answer. In Figure 2, the concept of DP is illustrated.

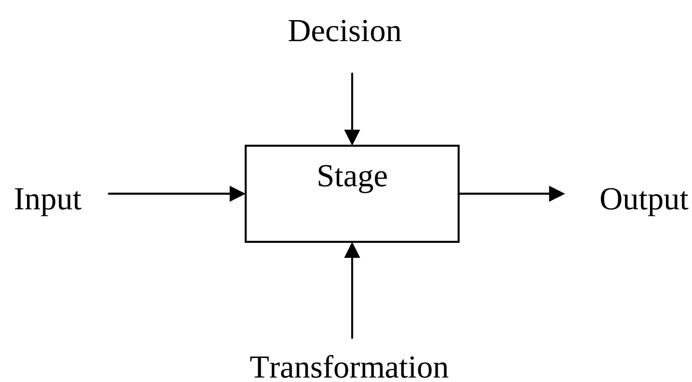

FIGURE 2. Dynamic Programming basic concept.

The point at which we make the decision is denoted as the stage and our input parameters are denoted as the state. In each stage, we are forced to make a decision. This decision has an equation and is represented as a return function. The return function will then depend on the state variable and the decision made at the stage. An optimal decision at that stage would be the decision which will yield a maximum or a minimum return for a given value of the state variable as in Figure 3 below.

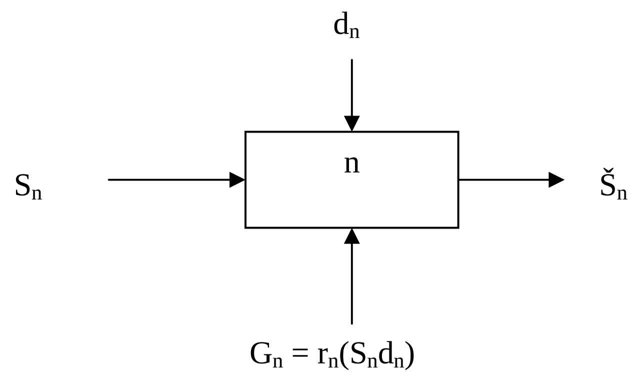

FIGURE 3. Dynamic Programming solution and decision process.

Where S_n = input stage
$\check{S}_n$ = output stage
n = stage number
d_n = decision
g_n = return function = $r_n(S_n d_n)$

In the area of power systems, DP has been applied, in [8], to economic dispatch using forward DP approach, unit commitment and hydrothermal scheduling. Recently, DP has been proven to solve bidding strategies in electricity spot markets [13] and applied to different types of generation facilities. DP is illustrated to solve hydrothermal scheduling problem below [8]. In this model, a single hydro plant operated in conjunction with a thermal system will show benefits of applying DP.

Let

{i} = the volume states at the start of the period j
{k} = the states at the end of period j
$TC_k(j)$ = the total cost from the start of the scheduling period to the end of period j for the reservoir storage
PC(i,j – 1:k,j)= production cost of the thermal system in period j to go from an initial volume to an end of period of final volume

The forward DP algorithm is then,

$$TC_k(0) = 0 \qquad (11)$$

and

$$TC_k(j) = \min\,[TC_i(j-1) + PC(i,j-1:k,j)] \qquad (12)$$

Some DP applications are shown in Table 3 for information.

Area of Applications	Objective Function	Constraints
Electricity Market Bidding Strategies [13]	Maximize profit	1.Generator capacity limits 2.Ramp rate limits 3. Demand limits
System Operations [8]	1. Minimize economic Dispatch 2. Minimize unit Commitment cost	1.Generator capacity limits 2.Generation equals Demand plus losses 3. Transmission losses 4. Ramp rate limits
Asst Management	Optimal Equipment Replacement	1.Equipment failure rates 2.Investment Costs 3.Maintenance and operating costs

TABLE 3. Summary of some Dynamic Programming applications in electric power engineering

III. Discussion

The application of OR techniques to a deregulated power industry is very essential. Thus, the instruction of OR courses to EE students who will manage the power industry in the future must be reformed and taken seriously. LP applications to power systems need linearization of non-linear variables. This will provide approximation to the arrived solution. IP, on the other hand, lend a helping tool for decision making in power systems. The “integer” output of the solution gives precision to operating limits and constraints associated with the power system problem. Electric power engineering needs knowledge of DP among graduates of EE. Since DP is used for applications of economic and technical importance, the EE student must have a vast grasp of the method.

IV. Conclusion and Recommendations

This paper has presented a framework for OR course instruction for EE students. Several key documents pertaining to the deregulation of the electric power industry in the Philippines were cited to put light to the said framework. Also, the TPEAME-EE calls for OR subject elective for EE students is of timely significance. The present instruction of OR to EE students was also reviewed and given appropriate solution through the framework. A framework of OR instruction consisting of Linear Programming, Integer Programming and Dynamic Programming was discussed. Theories and applications to electric power engineering were mentioned for information of OR instructors. Illustrative examples were also given accordingly.

The use of computer software in OR is highly recommended for use with the framework since power system problems are much of numerical computations if implored. Basically, large problems must be reduced to impart necessary knowledge to EE students. A course workbook will surely help OR instruction for EE students and is suggested.

V. Acknowledgements

The authors would like to thank: their respective families for the support and love; technical support provided by the College of Engineering and Architecture of Holy Angel University; and Ms. Terry Canlas of Engineering Library for the support and assistance.

VI. References

1. Republic Act No. 9136, Electric Power Industry Reform Act (EPIRA), available on line (www.erc.gov.ph)
2. Abaya, E., Amon, J., Coronado C, and Gil R., 1997, Technical Panel for Engineering, Architecture and Maritime Education for Electrical Engineering, Commission on Higher Education, Diliman, Quezon City, Philippines
3. Philippine Grid Code, Energy Regulatory Commission, San Miguel Avenue, Pasig City, Philippines, available on line (www.erc.gov.ph)
4. Philippine Distribution Code, Energy Regulatory Commission, San Miguel Avenue, Pasig City, Philippines, available on line (www.erc.gov.ph)
5. Wholesale Electricity Spot Market Rules, Energy Regulatory Commission, San Miguel Avenue, Pasig City, Philippines, available on line (www.erc.gov.ph)
6. J. R. McDonald and X. Wang, Modern Power System Planning, 1st edition, McGraw-Hill Book Co., 1994
7. Operations Research Book
8. A.J. Wood and B. F. Wollenberg, Power Generation Operation and Control, 2nd edition, John Wiley and Sons, New York, 1996
9. Askarian H. A. ,et al, A New Optimal Coordination Method for Overcurrent Relays, AUPEC 2001, Australia
10. Website, http://www.uclm.es/area/gsee/english/, Escuela Técnica Superior de Ingenieros Industriales, Universidad de Castilla—La Mancha, Ciudad Real, Spain
11. Chow M. Y., et al, Phase Balancing using Mixed Integer Programming, Institute of Electrical and Electronic Engineers (IEEE) Transactions in Power Systems, Vol. 13, No.4, November 1998
12. Website, http://www.eprl.engg.upd.edu.ph, Electric Power Research Laboratory, University of the Philippines, Diliman, Quezon City

13. Alvarado F. and Rajaraman, R., Optimal Bidding Strategy in Electricity Markets Under Uncertain Energy and Reserve Prices, PSERC Publication 03-05, available on line (www.pserc.org)

About the authors

Edwin B. Cano received Bachelor of Science in Electrical Engineering from Holy Angel University (HAU) in 1993. He graduated from Technological University of the Philippines with the degree of Master of Engineering-Electrical Engineering in 2002. He is a registered Professional Electrical Engineer and serves as the Vice President for Technical Affairs for the Institute of Integrated Electrical Engineers (IIEE)-Pampanga chapter. He presently works full-time at the Network Protection Department, System Operations, National Transmission Corporation (TRANSCO) and is an Adjunct Professor at College of Engineering of HAU. He is now a MSEE student at University of the Philippines in Diliman, Quezon City. His research interests are risk assessment and optimization applications in electric power system and energy markets.

Dhon G. Dungca graduated from De La Salle University-Taft with the degree of Bachelor of Science in Industrial Engineering. He is presently the Chairperson of the Industrial Engineering Department at HAU. He is also a student at HAU finishing his Master of Engineering-Industrial Engineering program. He is serving as the President of the Philippine Institute of Industrial Engineering (PIIE)-Angeles City chapter.