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Optimal Power Flow by using Distributed Generation in Six Buses Iraqi Network

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Abstract-The OPF problem is discussed in detail in the literature. It is also explained how various methods and techniques can be used to solve it. Finally, a detailed illustration of the LP optimization tool is provided. The complexity of the OPF problem is immense. It involves the various design, planning, and operation problems related to power systems. This report aims to provide an overview of the LP optimization method and its various applications. FOR full AC Increment method. Furthermore, a conceptual review of reactive power pricing was presented, as well as a suggested approach for incorporating the cost function into the goal function. Finally, a quick representation of the toolbox PSAT Simulator was presented, as well as the implementation of both methods on the 6-bus test system using a systematic process, and a comparison of both approaches during the OPF, as well as before and after the inclusion of cost function.

Keywords—OPF, optimal power flow, psat, power system analysis toolbox, LP, liner programming

I. INTRODUCTION

Before the introduction of the optimum approach to share the real load among several thermal productions with an overall capacity higher than the required generation was determined using the optimal power flow, economic dispatch (ED). The best or optimum way to schedule these units to achieve the lowest generating cost while adhering to the entire generation must meet total demand plus losses, according to the restriction.

Line overloading was a serious[1] concern and a threat to the economically dispatched power systems until the early 1960s when the network's capacity was nearing its maximum. To protect the system's security, further limits were implemented, and optimal power flow (OPF) was proposed[2]. "The determination of the whole state of the power system with an optimal operation within security limitations" is how an optimal power flow is defined. These restrictions could be described as active and reactive power generation boundaries, bus voltage limits, transformer tab rates, phase shift limits, transmission line thresholds, and possibly the ideal fuel cost and safety for running at that optimal point without breaching any restraints. The various constraints that are associated with the operation of power systems can be represented as different types of limits[3]. These limits can be used to determine the optimal point at which to operate safely and cost-effectively[4]. The problem grew in size and complexity as a result of these constraints[3]. This is solved, however, by combining a mathematical technique for optimization with a power flow calculation. Optimization is described as "the process of minimizing or maximizing an objective function," and it is accomplished using a mathematical optimization tool such as linear optimization, non-linear optimization, and a variety of other methods. The linear programming (LP) method is used to achieve linear optimization. Because of its ability to solve both linear and non-linear objective functions via linearization, as well as its simplicity of managing inequality constraints, LP is one of the most powerful optimization methods. [5].

II. THE POWER FLOW PROBLEM

The goal of the power flow problem is to identify unknown parameters in the network elements of a power system that is expected to be balanced and illustrated by a single line diagram. Hundreds of buses and branches make up the power system network, with impedances stated per unit on a common MVA basis[6].

In terms of node (bus) currents, the nodal admittance form of the network equations yields a complex linear simultaneous equation, resulting in non-linear equations that must be resolved utilizing iterative procedures. The power flow problem is solved using iterative approaches[7]:

- The Gauss Seidel formula.
- The Newton Raphson formula.
- Decoupled power flow solution.

For power system analysis and design, as well as planning and operation, power flow studies are essential. These studies include optimization, sensitivity analysis, economic analysis, voltage stability, transient stability, and contingency analysis. As previously stated, the unknown parameters in the power flow problem must be defined, and the types of buses in the network are used to classify these parameters. [8]. Each bus is related to four quantities:

- The magnitude of the bus voltage $|V|$.
- The phase angle of the voltage δ.
- The real power of the generator P.
- The reactive power of the generator Q.

The buses types are classified into:

The Slack bus: also known as the swing bus, serves as a reference bus for calculating the variances in generated power and loads induced by network losses. The voltage magnitude and phase angle are given in this bus, as well as the real and reactive power to be calculated.

Load buses, also known as P-Q buses, are used to determine the real and reactive powers, as well as the voltage magnitude and phase angle.

Regulated buses: also known as P-V buses or voltage-controlled buses, these buses are generator buses with real power and voltage magnitude specifications, as well as the generator reactive power restrictions. The actual power and phase angle to be used are also specified.

III. ECONOMIC DISPATCH

Best possible dispatch, also known as Economic dispatch, is a method of calculating generating unit scheduling in order to lower total operating costs while remaining within the constraints[9]. Total production must equal total demand plus losses[10]. The input-output (I/O) generation cost function causes the ED issue's nonlinearity, while the equalization requirement is the power balancing restriction and the inequality limitation is the generating capacity limits constraint.

Since the idea of scheduling generators to reduce total running costs became popular in the 1920s or perhaps earlier, the economic dispatch problem has existed[11]. Various methods were employed in 1930 to determine the most cost-effective network form: "the base load method" and "the best method." Optimal dispatch, also known as Economic dispatch, is a method of selecting generating unit scheduling to lower overall operating costs while adhering to the constraint that total generation must equal total demand + losses[12]. The input-output (I/O) generation cost function causes the ED issue's nonlinearity, while the equality constraint is the power balancing constraint and the inequality constraint is the generating capacity limits constraint[13]. The economic dispatch challenge has existed since the idea of scheduling generators to lower total running costs became popular in the 1920s or possibly earlier. In 1930, "the base load method" and "the best approach" were used to find the most cost-effective network form[14].

IV. OBJECTIVE FUNCTION

Many electric utilities prefer to use single or multiple-segment linear cost functions to depict their generating cost functions. These functions are represented by the curves in Figure 6.1. If we tried to utilize the lambda iteration search method on the single-segment cost function[15], we would always end up with Pmin or Pmax unless l exactly matched the incremental cost, in which case the value of P would be unknown. To address this issue, we have changed the way we dispatch. We begin by running all units at Pmin, then gradually increase the output of the unit with the lowest additional cost. We choose the next lowest incremental cost segment and raise its output if this unit approaches the right-hand end of a segment or achieves Pmax. Eventually, the unit's output will be raised until the total of all unit outputs matches the total load. At this stage, we assign the last unit to be changed to have a partially loaded generation for one segment. It's worth noting that if two units have the same incremental cost, we could just load them evenly, though any generation allocation to such units is arbitrary. To make this method go quickly, we can develop a table that lists the MW contribution of each segment of each unit (the right-hand end MW minus the left-hand end MW). The table is then sorted by incremental cost in increasing order. We don't have to travel back to the top of the table to seek the next segment because we're looking from the top down. This is a very quick mode of economic dispatch. We'll show how piecewise linear cost functions can be employed in a linear model in the next section.

V. CONSTRAINTS

We start with a nonlinear cost function shown in Figure 1. As shown in Figure2, we can represent this nonlinear function using a series of straight-line segments. The three segments for generator i have shown will be represented as *i*1, *i*2, and *i*3. The *Pi* variable is replaced with three new variables P_{geni1}, P_{geni2} and P_{geni3} . Each segment will have a slope designated S_{i1}, S_{i2}, S_{i3} (where $S_{i1} < S_{i2} < S_{i3}$); then the cost function itself is now represented as the sum of the cost at P_i^{min} plus the sum of the linear cost for each segment which is simply its slope times the P_{ij} variable. Then

$$F_i(P_i) = F_i(P_{imin}) + S_{i1}P_{i1} + S_{i2}P_{i2} + S_{i3}P_{i3} + S_{in}P_{in} \quad \ldots(1)$$

Where:

$$F_i(P_{imin}) = a + bP_{imin} + cP_{imin}^2$$

For the new values of the generation power Pi:

$$0 \leq P_{genik} \leq P_{genik}^{min} \quad \text{for } k=1,2,3$$

$$P_i = P_{imin} + P_{i1} + P_{i2} + P_{i3} + \cdots + P_{in} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$S_{ik} = \frac{F_i(P_{gen\ ik+1}) - F_i(P_{gen\ ik})}{(P_{gen\ ik+1}) - (P_{gen\ ik})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The cost function is now made up of a linear expression in the three variables P_{geni1}, P_{geni2}, P_{geni3}.

Because the slopes increase in value, the linear program will cause P_{genik} to be at its limit max

$P_{gen\ ik}^{max}$ before $P_{geni(k+1)}$ increases beyond 0.

VI. OVERVIEW OF PSAT

PSAT is a MATLAB toolkit for analyzing and controlling electric power systems. Power Flow, Continued Power Flow, Optimal Power Flow, Small Signal Stability Analysis, and Time Domain Simulation are all included in PSAT[16]. Graphical user interfaces (GUIs) may be used to evaluate all PSAT operations, and a Simulink-based library provides a user-friendly tool for network construction. The power flow routine, which also handles state variable initialization, lies at the heart of PSAT. Further static and/or dynamic analysis can be undertaken once the power flow has been solved. These are the routines:

1. optimal Power flow (OPF)
2. Power flow continuation (CPF)
3. Analysis of small-signal stability
4. Simulations in the time domain
5. Positioning of the phasor measuring unit (PMU).

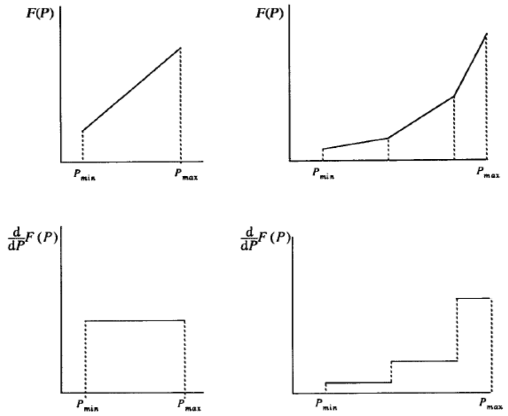

Fig. 1. Piecewise linear cost functions.

VII. THE 6-BUS SYSTEM DESCRIPTION:

The system has six buses, three producing units, and eleven transmission lines. Bus 1 is the slack (reference bus), buses 2 and 3 are P-V buses, and buses 4, 5, and 6 are load (P-Q) buses. The impedances are measured in per-units on a 100 MVA basis[17], with bus voltage restrictions ranging from 1.07pu to 0.95pu. The input data for the power flow and the generating cost functions are also provided[18].

$$F_1(P_1) = 213.1 + 11.669P_1 + 0.00533P_1^2$$

$$F_2(P_2) = 200 + 10.333P_2 + 0.00889P_2^2$$

$$F_3(P_3) = 240 + 10.833P_3 + 0.00741P_3^2$$

Unit 1 limits; $50 \le P1 \le 200$ MW,

Unit 2 limits; $37.5 \le P2 \le 150$ MW.

Unit 3 limits; $45 \le P3 \le 180$ MW.

We will be able to calculate the optimal power flow (OPF) utilizing LP with a load of 300 MW. The main distinction is that the solution will differ from that found using the normal method depending on the number of segments employed. For each cost function, we utilize 1, 3, 5, 10, and 50 segments in the following table, and you can see how the solution gets closer to the same answer as the number of segments grows[19].

TABLE I. DCOPF RESULT.

Bus	Pmin (MW)	Pgen (MW)	Pmax (MW)	Pload (MW)	Lambda ($/MWh)
1	50.000	72.643448	200	0	12.4434
2	37.500	118.693991	150	0	12.4434
3	45.000	108.662561	180	0	12.4434
Total generation cost					4145.2 $/h

Note that increasing the number of segments does not necessarily bring the solution closer to the exact solution. When going from two segments to three segments, the solution actually gets slightly worse in terms of total cost. This is simply because the breakpoints with three segments fall further from the true solution than the two-segment case. As the number of segments is increased to five, ten, and even fifty the solution comes very close to the exact solution.

VIII. PSAT SIMULINK LIBRARY EDITOR

The Simulink library is being used to create the system model as well as to change it by altering the components and data. [20].

This model is loaded in PSAT and the power flow analysis has been conducted for getting the results as shown below.

TABLE II. POWER FLOW REPORT.

POWER FLOW REPORT	
NETWORK STATISTICS	
Buses:	6
Lines:	11
Generators:	3
Loads:	3
SOLUTION STATISTICS	
Number of Iterations:	4.00
Maximum P mismatch [p.u.]	0.00
Maximum Q mismatch [p.u.]	0.00
Power rate [MVA]	100.00

TABLE III. POWER FLOW RESULTS

Bus		**Bus1**	**Bus2**	**Bus3**	**Bus4**	**Bus5**	**Bus6**
V	[p.u.]	1.07	1.05	1.05	1.02	1.02	1.02
phase	[rad]	0.03	0	-0.05	-0.06	-0.09	-0.09
P gen	[p.u.]	1.1	1.48	0.5	0	0	0
Q gen	[p.u.]	0.17	-0.2	0.18	0	0	0
P load	[p.u.]	0	0	0	1	1	1
Q load	[p.u.]	0	0	0	0.15	0.15	0.15
P gen	MW	110	148.31	50	0	0	0
Q gen	MVAR	16.74	-20.14	18.38	0	0	0
P load	MW	0	0	0	100	100	100
Q load	MVAR	0	0	0	15	15	15
VR	[p.u.]	0	-0.02	-0.02	-0.04	-0.05	-0.04

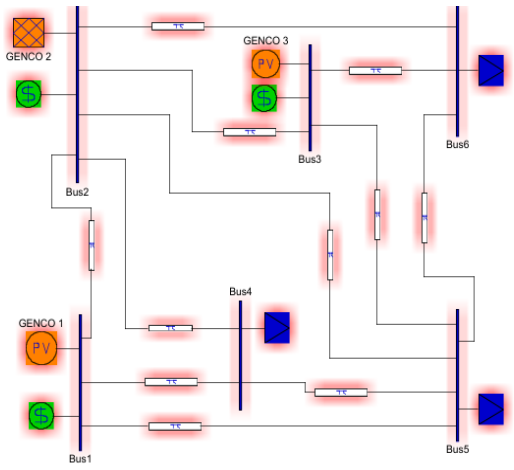

Fig. 2. Simulink 6 bus test system model

TABLE IV. TABLE 4A: LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	Q Loss
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus2	*Bus3*	*1*	0.21	-0.07	0	-0.06
Bus3	*Bus6*	*2*	0.52	0.17	0.01	0.01
Bus4	*Bus5*	*3*	0.07	-0.07	0	-0.08
Bus3	*Bus5*	*4*	0.19	0	0	-0.05
Bus5	*Bus6*	*5*	0.01	-0.04	0	-0.06
Bus2	*Bus4*	*6*	0.61	-0.03	0.02	0.01
Bus1	*Bus2*	*7*	0.16	0.01	0	-0.04
Bus1	*Bus4*	*8*	0.49	0.12	0.01	0
Bus1	*Bus5*	*9*	0.45	0.04	0.01	-0.01
Bus2	*Bus6*	*10*	0.5	-0.04	0.02	-0.01
Bus2	*Bus5*	*11*	0.33	-0.02	0.01	-0.01

TABLE V. TABLE 4B: LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	Q Loss
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus3	*Bus2*	*1*	-0.21	0.01	0.00	-0.06
Bus6	*Bus3*	*2*	-0.51	-0.16	0.01	0.01
Bus5	*Bus4*	*3*	-0.07	-0.01	0.00	-0.08
Bus5	*Bus3*	*4*	-0.18	-0.05	0.00	-0.05
Bus6	*Bus5*	*5*	-0.01	-0.02	0.00	-0.06
Bus4	*Bus2*	*6*	-0.59	0.04	0.02	0.01
Bus2	*Bus1*	*7*	-0.16	-0.05	0.00	-0.04
Bus4	*Bus1*	*8*	-0.48	-0.12	0.01	0.00
Bus5	*Bus1*	*9*	-0.43	-0.05	0.01	-0.01
Bus6	*Bus2*	*10*	-0.48	0.03	0.02	-0.01
Bus5	*Bus2*	*11*	-0.32	0.00	0.01	-0.01

TABLE VI. POWER EFFICIENCY P.U

P Flow in	P Flow out	efficiency
[p.u.]	*[p.u.]*	*%*
0.21	0.21	99.03%
0.52	0.51	98.95%
0.07	0.07	98.38%
0.19	0.18	97.90%
0.01	0.01	99.79%
0.61	0.59	97.24%
0.16	0.16	98.55%
0.49	0.48	97.67%
0.45	0.43	96.78%
0.50	0.48	96.84%
0.33	0.32	97.04%

IX. RESULTS AND DISCUSSION

The proposed method's performance is tested using a six-bus distribution system. Figure 1 depicts the structure of the 6bus network. The 6bus distribution system has only one generator. Three transformers and one shunt reactive power compensator are located at the slack bus in the system. The overall reactive power load was 45 Mvar, while the total real power load was 300 MW. After one hundred iterations, most of the time there would be no discernible improvement in the optimization outcome. However, to give the particles enough time to approach the global minimum, the optimization process' ending condition is set at two hundred iterations. The swarm has fifty members. In Figure 2, V is the voltage value at the slack bus or PV bus, and T is the transmission line for the range system. At the buses (1,2,3) are power injection. The buses (4,5,6) represent load. The PSAT modeling calculates all energy flow from the slack bus to the load bus. Also using a range system make the load flow more reliable and flexible at the same time to transfer the load.

X. CONCLUSION

In this paper, power flow simulations of six buses using PSAT are used. An analysis was conducted to calculate the optimal flow of energy and to calculate the transmission losses with the energy consumed by the load compared with the available generation. On the other hand, calculating the capacity spent with losses to provide generation gives the actual need for the system.

The system's transient behavior is determined by the placement of the energy sources and their connection to the best bus for minimizing losses.

This study demonstrates how voltage stability and optimal power flow studies can be carried out simultaneously. Furthermore, applying constraints to the current operating point reduces the space of feasible solutions, resulting in distinct optimal solutions in the maximum distance to collapse problem. It is proven the differences between saddle-node and limit-induced bifurcation. An optimized power flow method with voltage stability criteria is employed on a test system.

CONTRUBITION OF THE AUTHORS

The contributions of the authors to the article are equal.

CONFLICT OF INTEREST

There is no conflict of interest between the authors.

STATEMENT OF RESEARCH AND PUBLICATION ETHICS

Research and publication ethics were observed in this study

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