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Effect of Considering Transmission Losses in Economic Dispatch – A Case Study of Oman's Main Interconnected System

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Abstract: Economic dispatch is an important optimization problem in power system planning. This article presents an overview of the economic dispatch formulation, its objective, loss coefficient determination, and a case study. In the case study, different scenarios of the economic dispatch in the main interconnected system (MIS) of Oman were considered to highlight the importance of considering losses in the optimization process.

Keywords: Economic dispatch; Loss coefficients; Power systems; Main interconnected system.

تأثير احتساب الفاقد على التوزيع الاقتصادي للأحمال - دراسة حالة الشبكة الرئيسة المرتبطة في سلطنة عمان

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الملخص: يعد التوزيع الاقتصادي للأحمال هوالمشكلة الاهم في تخطيط نظام الكهرباء. تعمل هذه المقالة على تقديم لمحة عامة عن صيغة االتوزيع الاقتصادي للأحمال وتحديد هدفها و معامل الفقدان و دراسة حالة. و يتم اخذ الاعتبار في دراسة الحالة هذه، سيناريوهات مختلفة للتوزيع الاقتصادي للاحمال في النظام الرئيسي المترابط في عمان و ذلك لتسليط الضوء على أهمية احتساب الفواقد المترتبة على عملية التحسين.

الكلمات المفتاحية : التوزيع الاقتصادي، معاملات الفقدان، أنظمة الطاقة، الشبكة الرئيسة.

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Symbols and Abbrevations

IPP	:	Independent Power Producer
LFC	:	Load Frequency Control
MIS	:	Main Interconnected System of Oman
OETC	:	Oman Electricity Transmission Company
OPWP	:	Oman Power and Water Procurement Company
SAOC	:	Closed joint stock company
a_j, b_j, & c_j	:	Coefficients of the quadratic cost function
$B, B_0, \& B_{00}$	:	Coefficients of the B-loss formula
F_l^t	:	Apparent power flowing through transmission line *l* during the interval *t*
F_l^{max}	:	Upper limit of the power flow along line *l*
F_{cost}	:	Total operating cost
F_j	:	Operating cost of generation unit *j*
N_g	:	Total number of generation units in the power system
P_D	:	Total power demand
P_j	:	Output power of generation unit *j*
P_j^{min}	:	Minimum output limit of unit *j*
P_j^{max}	:	Maximum output limit of unit *j*
P_L	:	Total power losses
S_j^t	:	Spinning reserve contribution of unit *j* during time interval *t*
SR^t	:	System spinning reserve requirement for interval *t*

1. Introduction

Power systems have different types of generation facilities and load profiles. To maintain the stable operation of power systems, the aggregated output of online generation units and the total demand must be balanced in real time. When the net generation is higher than the net demand, the system frequency increases and vice versa (Zhu 2015). The total loads in power systems experience different chronological variations: seasonally, on weekends and weekdays, and within each day (during peak and off-peak hours) (Albadi and El-Saadany 2011). Variations in demand occur even on a second-by-second basis. To cope with these chronological variations, the outputs of the different online generation units experience cycles of operation according to the forecasted net load.

Power systems have different operational planning time frames: unit commitment (weeks and days) (Padhy 2004), economic dispatch (hours) (Gaing 2003), and frequency regulation (minutes and seconds) (Kumar and Kothari 2005). Unit commitment is the optimum selection of online dispatchable generation units to satisfy different operating constraints. Once online generation units are selected, economic dispatch is used to schedule the output of each unit to follow hourly load variations. It is worth mentioning that different utilities conduct economic dispatch at different time intervals. Some utilities have an hourly dispatch while others consider shorter dispatch intervals. During real-time operation, the mismatch between demand and scheduled generation is covered using regulation services. These include turbine-governor control and load frequency control (LFC).

Figure 1 shows a system that consists of N_g number of generating units serving an aggregate electrical load. Since the combined capacity of these units is normally higher than that of the load, there exists an infinite number of output combinations to satisfy the load. The objective of the economic dispatch is to determine the output of each generation unit so that the total operating cost is minimized while relevant constraints are satisfied (Zhu 2015). Other objectives of the economic dispatch include the minimization of emissions, the maximization of profit by reducing the total cost, and the maintenance of system stability and security.

If the transmission network of the power system under study is considered, the total demand that the generation units must satisfy includes transmission losses (George 1943). The value of transmission losses is a function of the economic dispatch decision variables, which can be determined using power-flow techniques (Saadat 1999). However, transmission losses can be included in the optimization procedure using different methods. One of these methods is the loss coefficient technique.

The main contributions of this article includes modeling and simulating the main inter-connected system (MIS) of Oman for economic dispatch purposes, calculating the loss coefficients of the system, and including losses in the economic dispatch of the MIS.

Following this introduction, the article presents a review of the economic dispatch formulation in section II. System data are presented in section III, and simulation results are discussed in section IV. Finally, the conclusions are presented in section V.

2. Economic Dispatch Formulation

2.1 Mathematical Formulation of Economic Dispatch

The objective function of an economic dispatch problem is to minimize the total operating cost (F_{cost}), which is the summation of individual generation units' operating/fuel costs ($F_j(P_j)$) (Zhu 2015).

$$F_{cost} = \sum_{j=1}^{N_g} F_j(P_j) \quad (1)$$

The operating cost of each generation unit is given as a function of its output power (P_j) and is modeled as a quadratic function.

$$F_j(P_j) = a_j + b_j P_j + c_j P_j^2 \quad (2)$$

where a_j, b_j, and c_j represent the cost coefficients of the jth generating unit, P_j represents the real output of the jth generating

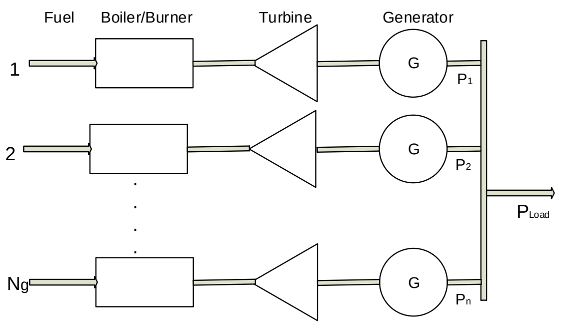

Figure 1. Generating units serving an electrical load.

unit (in MW), and N_g is the total number of generation units in the power system under study. These cost coefficients can be obtained from the heat rate data of generation units at different operating points and the price of fuel.

The optimization problem has the following constraints:

- Power balance constraints

$$\sum_{j=1}^{N_g} P_j = P_D + P_L \quad (3)$$

where P_D is the power demand and P_L represents the power losses.

- Generation unit limit

$$P_j^{min} < P_j < P_j^{max} \quad j = 1 \dots N_g \quad (4)$$

where P_j^{min} and P_j^{max} are unit *j* minimum and maximum limits, respectively.

- Spinning reserve requirement

$$\sum_{j=1}^{n} S_j^t \geq SR^t \quad t = 1 \dots N \quad (5)$$

where S_j^t is the spinning reserve contribution of unit *j* during the time interval *t*, and SR^t is the system spinning reserve requirement for interval *t*. S_j^t can be expressed as $P_j^{max} - P_j^t$ where P_j^t is unit *j* output during time *t*.

- Network security constraints (voltage limit constraints, e.g. +/- 10% in the MIS (OETC 2010).

- Line capacities

$$F_l^t \leq F_l^{max}; t = 1 \dots N_T \quad (6)$$

where F_l^t is the apparent power flowing through transmission line *l* during the interval *t*, and F_l^{max} is the upper limit of the power flow along line *l*.

It is worth mentioning that these limits are thermal limits of the transmission lines and can be found in OETC capability statement (OETC 2014.

2.2 *Loss Formula*

When transmission line distances are small, transmission losses can be ignored and the optimal dispatch of generation units can be achieved without considering the transmission system losses. However, in large interconnected systems, transmission losses play a major role in the optimal dispatch of generation units. Hence, the transmission line losses of large networks need to be considered in the optimal dispatch of generation units.

There are several methods by which losses become part of the dispatch decision. George was the first to develop the simplest form of the loss equation (George 1943):

$$P_L = \sum_{n=1}^{K} \sum_{m=1}^{K} P_m B_{mn} P_n \quad (7)$$

Alternatively,

$$\mathrm{P_L} = \sum_{\mathrm{i=1}}^{\mathrm{NG}} \sum_{\mathrm{j=1}}^{\mathrm{NG}} \mathrm{B}_{ij} \mathrm{P}_{Gi} \mathrm{P}_{Gj} \quad (8)$$

where B_{ij} and B_{mn} are called loss coefficients.

Attempts to obtain a more accurate expression of power system losses were made by adding linear terms and a constant to the original expression. These resulted in the *B* matrix loss formula, which was introduced in the beginning of 1950s as a practical method for the computation of losses and incremental losses (Wood and Wollenberg 2012). After the addition of linear terms and a constant to the original expression, the following loss formula was obtained:

$$P_L = P^T [B] P + B_0^T + B_{00} \quad (9)$$

where

P is the vector of all generator bus net MW, $[B]$ is the square matrix of the same dimension as P,B_0 is the vector of the same length as P, B_{00} is the constant.

This equation can be rewritten as follows:

$$P_L = \sum_i \sum_j P_i B_{ij} P_j + \sum_i B_{i0} P_i + B_{00} \quad (10)$$

Alternatively, it can be rewritten as follows:

$$P_L = \sum_{n=1}^{K} \sum_{m=1}^{K} P_m B_{mn} P_n + \sum_{n=1}^{K} P_n B_{n0} + B_{00} \quad (11)$$

There are three main methods for obtaining the loss formula coefficients (George 1943; Hill and Stevenson 1968; Yang, Hosseini, and Gandomi 2012). The first method is the tensor analysis method (Yang, Hosseini, and Gandomi 2012), the second method is the A_{jn} method (Hill and Stevenson 1968), and the third method is the Kron-Kirchmayer method, which Kron developed and Kirchmayer adapted (Abdelaziz *et al*. 2008; Saadat 1999; Wood and Wollenberg 2012).

Kron 1951) presented the mathematical formulation of the tensor analysis method, and Hill and Stevenson (1968) explained the mathematical formulation of the A_{jn} method. Furthermore, George (George 1943) explained Kron-Kirchmayer method. Many researchers have used the Kron-Kirchmayer method to determine the loss coefficients (Dike, Adinfono and Ogu 2013; Su and Lin 2000; Yang, Hosseini and Gandomi 2012). The same method was used to find the loss coefficients for the system under consideration, that is, the main interconnected system of Oman. Once the coefficients were obtained, it was possible to determine the economic dispatch. It is worth mentioning that loss coefficients are load-specific; therefore, they should be updated for different loading conditions.

3. Systems Data

The test system (the main interconnected system of Oman) data were obtained from two sources: the Oman Power and Water Procurement Company SAOC (OPWP) (OPWP 2016a) and the Oman Electricity Transmission Company SAOC (OETC) (OETC 2016).

3.1 Generation Units

The transmission system is supplied with electricity generated at eleven gas-based power stations (open cycle and closed cycle) at Ghubra, Rusail, Sur, Wadi Al Jizzi, Manah, Al Kamil, Barka I, Barka II, Barka III, Sohar I, and Sohar II. In addition, the transmission system is connected directly to large customers with generation facilities, for instance, Sohar Aluminium, PDO, Sohar Refinery, OMCO, and OMIFCO (OETC 2014).

Some details of the existing generation units are available in the recent issue of "OPWP 7-year statement 2016-2022" (OPWP 2016b) and in previous issues. Other details are available in OETC's "Five-Year Annual Transmission Capability Statement (2014-2018)" regarding the MIS system (OETC 2014). Table 1 shows a summary of the eleven power stations connected to the MIS of Oman and their net generation capacity in 2014.

The fuel cost coefficients of all the generation units were based on estimated values from the heat rate curves received from OPWP. It is worth mentioning that, to preserve confidentiality, the heat rate values were indicative rather than actual. A price of $1.5/MMBtu for the fuel (natural gas) was used to obtain the fuel cost data. Then, a curve-fitting technique was used to obtain the fuel cost parameters for each generation unit. An example of a single-cycle generation unit is shown in Table 2 and Figure 2. The same procedure was conducted for all generation units in the system.

3.2 Transmission System

The OETC owns and operates the MIS's transmission network. Moreover, the OETC is responsible for balancing generation and demand at all times of the day for the economic dispatch of power. It accomplishes this role through the OETC Load Dispatch Centre (LDC), which is located in Al Mawaleh, Muscat. Currently, the system has three voltage levels: 132 kV, 200 kV, and 400 kV. The transmission system data are available in the OETC's 5-year annual capability statements, for instance, the 2014-2018 statement (OETC 2014). A summary of the transmission system in 2014 is shown in Table 3.

The OETC transmission system is also interconnected with the Sohar Aluminium system at 220 kV and the PDO transmission network at 132 kV via a single-circuit overhead line. The available data include the length of every line (km) between the substations, the resistance (Ω/km), the inductive reactance (Ω/km), and the capacitive susceptance (μS/km).

The power-flow model of the transmission system was built in MATLAB. Details of the MIS transmission system data are given in the appendix (Tables A1 and A2).

4. Simulation Results

A case study of the Main Interconnected System of Oman was conducted, and it included losses within the dispatch decision. It is worth mentioning that this simulation was conducted to determine the optimal dispatch for the peak-hour load of 2014.

The Lambda (λ) iteration method, based on Lagrange relaxation, is used to solve this optimization problem. This method starts by assuming an initial value for the system incremental fuel cost (λ), and calculating output power of all generation units (P_j) as a function of λ. Then, the value of λ is updated based on Newton-Raphson method considering the power balance mismatch. The process continues until the prescribed tolerance is reached (Saadat 1999).

The load data for all buses were obtained from the OETC annual capability statement (OETC 2014). The details of the load are given in the appendix (Table A3). The MATLAB software package was used in this study.

Three scenarios were considered in the economic dispatch.

Table 1. Power stations connected to the MIS of Oman.

Power Plant	Net Power Generation (MW)	Remarks
Al Kamil	282	Al Kamil is an IPP and was commissioned in 2002. The station comprises three GE PG9171E gas turbines (site rating: 94.1 MW) operating in open cycle
Manah	273	The United Power Company owns Manah. When commissioned in 1996, it was the first IPP to be built in Oman. The station comprises three GE PG6541B gas turbines (with each site rated at 28.8 MW) and two GE PG9171E gas turbines (ratings of 93.5 MW)
Wadi Al Jizzi	324	Wadi Al Jizzi Power Station comprises eleven gas turbines (with gross site ratings in the range of 19.2-32.5 MW) and all operate in open cycle. The units were installed progressively from 1982.
Sohar I	605	Sohar I Power Plant is an IPP and was commissioned in 2007. There are three gas turbines, each with a 138.7-MW capacity, and a steam turbine with a 220-MW capacity. All units have been operational since 2007.
Sohar II	745	Sohar II Power Plant is an IPP and was commissioned in 2012. There are two gas turbines, each with a 247.5-MW capacity, and a steam turbine with a 249.9-MW capacity. They have all been operational since 2013.
Barka I	434	AES (ACWA now) commissioned Barka 1 in 2003. It was developed as an independent water & power plant (IWPP). The power plant comprises two Ansaldo V94.2 gas turbines (manufactured under licence from Siemens) and a steam turbine operating in combined cycle.
Barka II	681	Barka II is an independent water & power producer (IWPP) and was commissioned in 2009. There are three gas turbines, each with a 130-MW capacity, and two steam turbines, each with a 161-MW capacity.
Barka III	745	Barka III is an IPP and was commissioned in 2012. There are two gas turbines, each with a 247.5-MW capacity and a steam turbine with a 249.9-MW capacity. They have all been operational since 2013
Sur	2000	Sur is an IPP and was commissioned in 2014. There are five gas turbines, each with a 244.4-MW capacity, and three steam turbines with capacities ranging between 156.8 and 310.7 MW.
Rusail	687	The power station has eight Frame 9E gas turbines installed and operating in open cycle. The gross site rating of the units varies from 81.5 MW to 95.9 MW. The units were installed progressively between 1984 and 2000.
Ghubra	406	Ghubra power plant has 2 steam turbines (each with a 29.2-MW rating) and 12 gas turbines (with ratings ranging from 16-88.6 MW).

Table 2. Example of estimated cost curve data for a 90-MW single-cycle generation unit.

Operating point from rating	Heat Rate (MBtu/kWh)	Fuel Consumption (MMBtu/hr)	Fuel Cost ($/hr)
30 %	16,467	395.5	593.20
65 %	10,784	630.8	946.26
100 %	10,431	938.8	1408.2

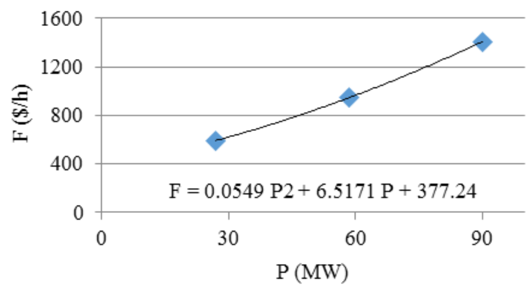

Figure 2. Estimated fuel cost parameters of a single-cycle generation unit.

In Scenario 1, losses were considered and calculated using B-coefficients in the Kron-Kirchmayer method.

- Scenario 2 involved simulating the current practice in the MIS, where losses are considered as a fixed load and are not included in the optimization procedure.
- Scenario 3 involved simulating the system performance when network losses were not considered at all in the dispatch procedure.

Figures 4 and 5 show the output of power generation for different units in the Rusail, Ghubra, Al Kamil, Manah, and Barka I power plants. Figure 4 shows the optimal output of power generation units for the Sohar I, Sohar II, Barka II, Barka III, and Sur power plants in the three scenarios.

There are some differences between the outputs of the generation units in the three scenarios. It is clear that the total dispatched power when the network losses are considered as a fixed load (Scenario 2) is higher than the total dispatched power associated with the two other scenarios in most of the power plants.

It is worth mentioning that considering losses in the optimization process (Scenario 1) requires slightly more execution time than other scenarios. A comparison of the number of iterations and execution time for the three scenarios are presented in Table 4.

Figure 5 shows the total dispatched power in MW for the three scenarios. It is clear that the overall power generation output when one considers the losses as a fixed load (Scenario 2) is higher than the optimal dispatch power generation when one considers the network loss using B coefficients (Scenario 1) by 48 MW. This result demonstrates that transmission losses should be considered in the economic dispatch process in the MIS.

Figure 6 shows the overall fuel cost comparison of Scenarios 1 and 2. The overall cost of power generation when one considers the losses using B coefficients (Scenario 1) is lower than the overall cost of the optimal dispatch of power generation when one considers the losses as a fixed load (Scenario 2) by \$645.62/hr. However, as was mentioned, the generation units' cost data were merely indicative values, not their actual values.

Figure 7 presents a comparison of the results of the current dispatch practice and those of the proposed dispatch practice that considers the network losses for each power station in the MIS.

Table 3. OETC transmission system assets.

Asset	Size	Quantity/Units
Overhead Transmission Lines	220 kV	1,454.4 Circuit-km
	132 kV	3,051.06 Circuit-km
Underground Cables	220 kV	61.6 Circuit-km
	132 kV	98.681 Circuit-km
Transformer Capacity	220/132	8,630 MVA
	220/33	320 MVA
	132/33	10,541 MVA
	132/11	150 MVA
Interconnection Grid Stations	220	Five
Grid Stations	220/132	Two
	220/33	One
	220/132/33	Seven
	132/33	Forty
	132/11	One

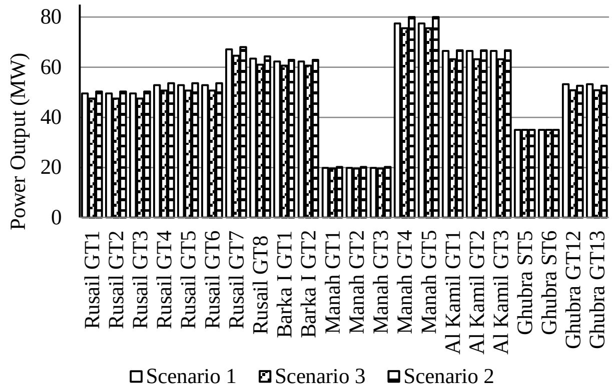

Figure 3. Dispatched power for the three scenarios (Rusail, Ghubra, Al Kamil, Manah, and Barka I power plants).

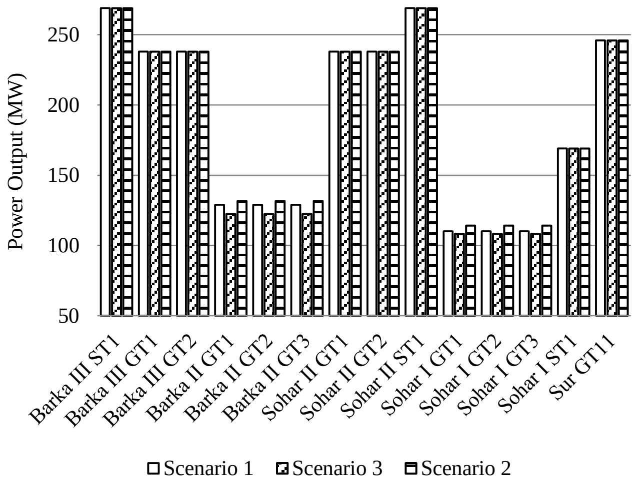

Figure 4. Dispatched power for the three scenarios (Sohar I, Sohar II, Barka II, Barka III, and Sur power plants).

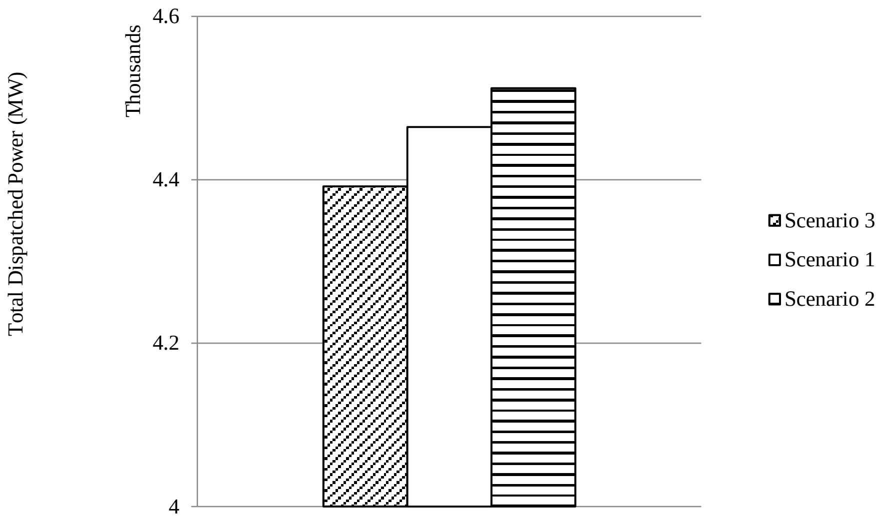

Figure 5. Comparison between the three scenarios' total dispatched power values.

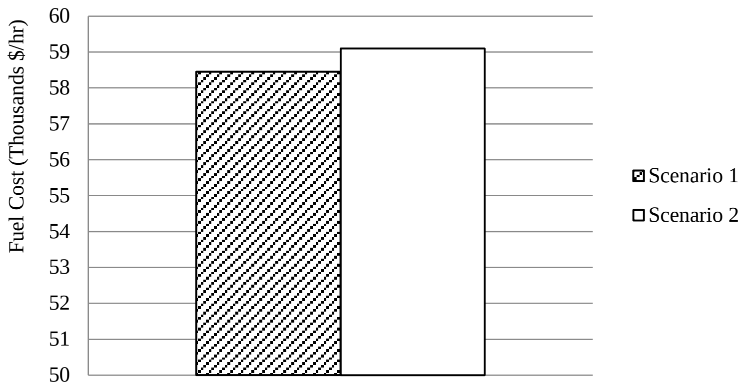

Figure 6. Comparison between the overall costs associated with Scenario 1 and Scenario 2.

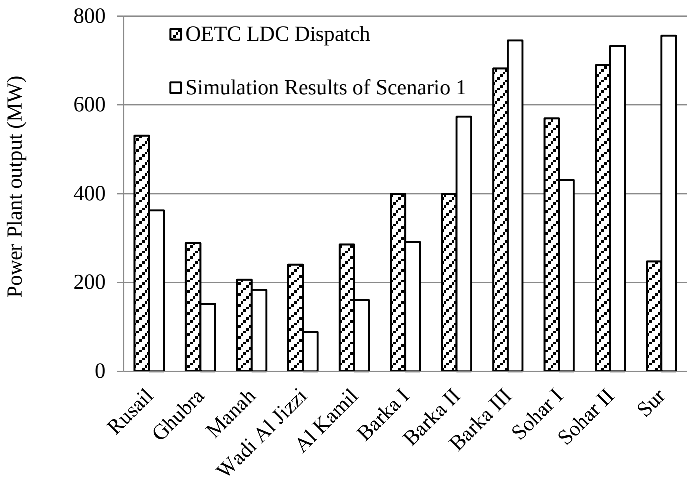

Figure 7. Comparison of the current dispatch practice and the proposed dispatch practice.

Table 4. Computational requirements of different scenarios.

Scenarios	Scenario 1	Scenario 2	Scenario 3
Number of iteration	9	6	5
Execution time	6.03 s	5.74 s	4.97 s

Simulation results show that the outputs of some power plants, such as Sohar II, Barka III, Barka II, and Manah, are more in line with Scenario 1 (the proposed practice) than the current practice of OETC LDC. On the other hand, the current practice results in the production of more power in other power plants, for instance, the Rusail, Ghubra, Wadi Al Jizzi, Al Kamil, Barka I, and Sohar 1 power plants.

These differences are attributable to (1) the inclusion of losses in the optimization procedure of Scenario 1 and (2) failure to consider water production and voltage support requirements in the simulation.

5. Conclusion

In this paper, the economic dispatch problem, its formulation, and its objectives and constraints were reviewed. The main interconnected system (MIS) of Oman was modelled to find the optimal dispatch of power generation at a selected hour on a selected day using the MATLAB software package. Furthermore, different methods for obtaining network loss coefficients were discussed. The loss coefficients of the MIS were determined and the optimal dispatch of the power generation units was found, taking the losses into consideration. This was compared with the current practice of dispatching generation units. It was demonstrated that considering the losses in the optimization procedure resulted in the reduction of the total dispatched power, reducing the cost by $645/hr.

Conflict of Interest

The authors declare no conflicts of interest.

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Appendix

Table A-1. MIS 2014 Overhead Line Data.

From Substation	To Substation	Voltage (kV)	Length (Km)	R [Ω/km]	X [Ω/km]	B [μS/km]
Barka Power station	Filaj	220	10	0.0258	0.321	3.82
Barka Power station	Filaj	220	10	0.0258	0.321	3.82
Filaj	Airport Heights	220	34	0.0258	0.321	3.82
Airport Heights	Misfah	220	16	0.0258	0.321	3.82
Misfah	MSQ	220	26	0.0258	0.321	3.82
Misfah	Jahloot	220	54.9	0.0258	0.321	3.82
MIS	SIS	220	107	0.0258	0.321	3.82
SPS	SIS	220	38	0.0258	0.321	3.82
Al Wasit	SIS	220	66	0.0258	0.321	3.82
Blue City	MIS	220	45.3	0.0258	0.321	3.82
Filaj	Blue City	220	33.2	0.0258	0.321	3.82
Al Wasit	Ibri	220	145	0.0258	0.321	3.82
Sohar IPP-2	SIS	220	36.9	0.0258	0.321	3.82
Barka IPP-3	Misfah	220	58.2	0.0258	0.321	3.82
Al Kamil	JBB Ali	132	55	0.04283	0.2821	3.98
Al Kamil	Mudharib	132	51.2	0.04283	0.2821	3.98
Al Kamil	Sur	132	73.1	0.04283	0.2821	3.98
Barka Main	Filaj	132	6.3	0.04283	0.2821	3.98
Dank	Al Hail	132	52.6	0.04283	0.2821	3.98
Filaj	Muladha	132	46.5	0.04283	0.2821	3.98
Izki	Mudaybi	132	62.1	0.04283	0.2821	3.98
Izki	Nizwa	132	31.1	0.04283	0.2821	3.98
Manah	Nizwa	132	19.7	0.04283	0.2821	3.98
Airport Heights	Seeb Main	132	7.8	0.1472	0.4111	2.6
MIS	Khabourah	132	53.4	0.04283	0.2821	3.98
Mabalah	Barka Main	132	11.6	0.04283	0.2821	3.98
MS Qaboos	Jahloot	132	44	0.04283	0.2821	3.98
MS Qaboos	Wadi Adai	132	8.2	0.04283	0.2821	3.98
Mudhabi	Mudharib	132	60.1	0.04283	0.2821	3.98
Muladha	MIS	132	11.4	0.04283	0.2821	3.98
Nizwa	Bahla	132	32	0.0857	0.3948	2.85
Nizwa	Ibri	132	123.5	0.04283	0.2821	3.98
Rusail	Mabalah	132	13.1	0.04283	0.2821	3.98
Rusail	Sumail	132	31.2	0.04283	0.2821	3.98
Rustaq	Muladha	132	29.5	0.04283	0.2821	3.98
SIS	Sohar Grid	132	27.5	0.04283	0.2821	3.98
Sohar Grid	Wadi Jizzi	132	24.7	0.04283	0.2821	3.98
Sumail	Izki	132	61	0.04283	0.2821	3.98
Wadi Adai	Al Falaj	132	3	0.04283	0.2821	3.98
Wadi Jizzi	Al Wasit	132	36.7	0.0972	0.3168	3.8
Wadi Kabir	Wadi Adai	132	6	0.0857	0.3948	2.85
Manah	Adam	132	47	0.04283	0.2821	3.98
Boushar	MS Qaboos	132	1.7	0.04283	0.2821	3.98
Ghubrah	MS Qaboos	132	1.7	0.04283	0.2821	3.98
Wadi Jizzi	Liwa	132	28	0.04283	0.2821	3.98
Liwa	Shinas	132	20	0.04283	0.2821	3.98
Khabourah	Saham	132	40	0.04283	0.2821	3.98
Saham	SIS	132	30	0.04283	0.2821	3.98

Al Wasit	Wadi Sa'a	132	32.0	0.1503	0.4101	2.83
Wadi Sa'a	Dank	132	56.5	0.1503	0.4101	2.83
Jahloot	Yitti	132	25.1	0.0258	0.321	3.82
Rusail	Misfah	132	10.0	0.04283	0.2821	3.98
Misfah	Wadi Adai	132	36.0	0.04283	0.2821	3.98
Filaj	Nakhal	132	26.0	0.04283	0.2821	3.98
Al Wasit	Buraimi	132	30.73	0.04283	0.2821	3.98
MS Qaboos	Qurum	132	10	0.04283	0.2821	3.98
Qurum	Muttrah	132	10	0.04283	0.2821	3.98
Ibri	Dank	132	55	0.04283	0.2821	3.98
Jahloot	Quriyat	132	50	0.04283	0.2821	3.98

Table A-2. 2014 MIS cable data.

From Substation	To Substation	Voltage (kV)	Length (km)	R [Ω/km]	X [Ω/km]	B [μS/km]
SPS	SIS	220	3	0.01074	0.312	91.11
SPS	Sohar Industrial Area 'A'	220	3	0.01074	0.321	91.11
Blue City	MIS	220	6	0.01074	0.321	91.11
Filaj	Blue City	220	6	0.01074	0.312	91.11
Sohar IPP-2	SIS	220	2.6	0.01074	0.321	91.11
Barka IPP-3	Misfah	220	10.2	0.01074	0.321	91.11
Airport Heights	Seeb Main	132	9	0.04282	0.08361	122.522
Mawellah	Rusail	132	7.3	0.04282	0.08361	122.522
Sohar Industrial Area 'A'	Sohar Refinery Co.	132	2.2	0.04	0.08	122.52
Wadi Kabir	Wadi Adai	132	1.63	0.04	0.143	64.7
Ghubrah	Boushar	132	2.323	0.04	0.08	122.52
Boushar	MS Qaboos	132	1.5	0.04	0.08	122.52
Ghubrah	MS Qaboos	132	4.8	0.04	0.08	122.52
Airport Heights	Wave	132	8.806	0.04	0.08	122.52
Al Wasit	Buraimi	132	5.47	0.04	0.08	122.52
Qurum	Muttrah	132	3.5	0.04	0.08	122.52

Table A-3. Peak Load and Capacitor Data in 2014.

Grid Stations	P Load (MW)	Q Load (MVAr)	Cap (MVAr)
Barka-132 kV	165	16	25
Nakhal-132 kV	62	6	25
Blue City – 220 kV	53	16	0
MIS – 132 kV	141	23	0
Muladah – 132 kV	134	5	30
Rustaq – 132 kV	117	7	0
Khabourah-132 kV	153	23	10
Saham 132 kV	112	15	0
SIA 220 kV	-40	-4.9	0
SIA 132 kV	47	8	0
Sohar main 132 kV	164	20	20
Liwa 132 kV	138	24	0
Shinas	85	15	25
Mahdah – 132 kV	12	7	0
Burimi 1 - 132 kV	50	8	0
Burimi 2 – 132 kV	50	8	35
Wadi Saa – 132 kV	11	6	0

Dank -132 kV	18	2	10
Al Hail – 132 kV	52	9	10
Ibri – 132 kV	104	9	10
Nizwa and PDO load connected to Nizwa	139	18	0
Bahla	104	9	0
Izki	61	14	0
Adam	39	2	0
Samail	78	17	0
Mudabi	110	18	0
Mudayrib	141	4	0
JBB	143	1	0
Sur and Omifco Load	117	4	0
MSQ – 132 kV	135	16	35
Old Gubrah	20	11	0
New Ghubrah	74	33	0
Bosher – 132 kV	226	36	40
Airport Hight – 132 kV	87	9	30
Mwalleh North – Authibah	14	1	0
Rusail PS – 132 kV	121	34.2	0
Misfah	5	13	0
Wadi Adai	121	19	35
Al Falaj	68	10	35
Wadi Kabeer	110	18	35
Matrah	47	25	0
Qurum	18	9	20
Mwalleh south-1	210	16	20
Seeb 132 kV	133	42	0
Mobillah	104	12	30
Jahloot	76	7	25
Yitti	15	3	0
Quryat	45	-11	0

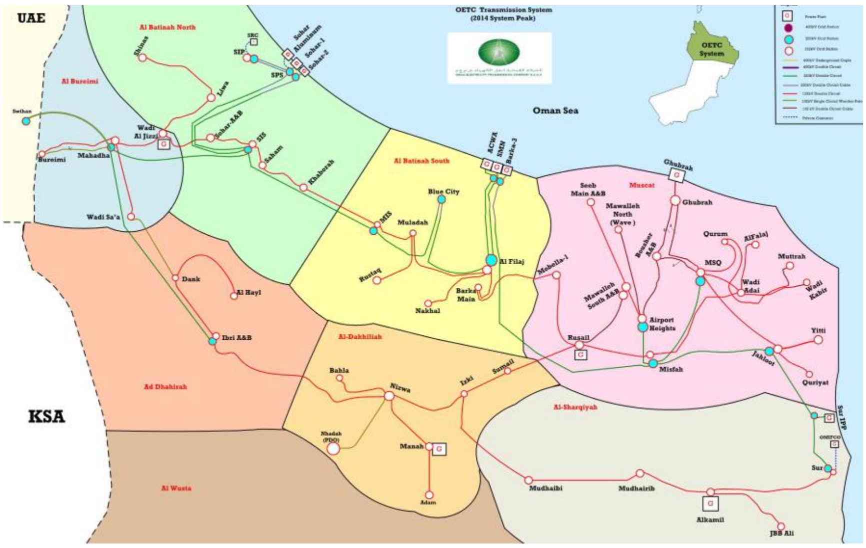

Figure A-1. MIS transmission system in 2014.