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Energy and Capacity Saving Potential in the Residential Sector of Oman

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Abstract. The substantial rise in Oman's load in recent years prompted researchers to investigate ways to reduce the construction of new power plants. Reducing the electricity consumption during the peak hours will provide the flexibility to lower the need of the generation units to be added on the system. This paper aims to find out the energy saving potential from the residential sector of Oman, specifically Main Interconnected System (MIS) load. Usually, the annual report circulated by the Authority for Public Service Regulation (APSR) provides the statistics of demand consumed. It states that about 45.2% accounts for residential consumption in 2021. A survey from different papers that emphasize the valuable contribution of energy savings from the residential sector is carried out. WASP-IV software is used to conduct the optimization generation expansion plan for a 20-year period. Another case is studied for the 25.2% decrease in home building consumption. The methodology is explained, as are the assumptions and constraints of the study. The results show a noticeable decrease in the total generation cost, environmental cost, and LOLP percentage for the energy saving case study compared with the base case.

Key words. Generation Expansion Plan, Residential Energy Saving.

1. Introduction

Oman's power systems comprise three areas: the Mian Interconnected System (MIS), which covers the northern side of Oman; the Dhofar Power System (DPS); and the Rural Area Electricity Company (RAEC), which is called TANWEER and covers the rural areas of Oman. According to the Annual Report 2021 of APSR, 31,471,215 MWh accounts for MIS-2021 [1]. Around 14,216,353 MWh were consumed by the residential sector, or 45.2% of the total consumption in the MIS accounts [1].

Due to both economic and demographic expansion, there will be a considerable increase in the amount of electricity consumed on the residential side. This prompts research into energy-saving strategies for the residential sector to lower the cost of future generation and transmission expansion processes. Many methods can be utilized to accomplish energy savings in houses. For example, from a design perspective, the insulation for the walls and roof, highly reflective coatings, green roofs and walls, shading, and responsive facades are all important, in addition to identifying and promoting energy-efficient air conditioners and lights. Demand Side Management (DSM) is considered another measure that contributes to energy savings. DSM involves such actions to control the load and enhance the load factor [2]. DSM's strategic planning aids in managing and controlling the rising load demand from electricity users. The DSM primarily focuses on training electricity users to change their usage habits in order to lessen the strain on the main grid for the consumer's uninterrupted power supply [2]. In 2017, Oman implemented the Cost Reflective Tariff (CRT), which is regarded as a kind of DSM [1].

According to the Sultanate of Oman's National Strategy for an Orderly Transition to Net Zero report that was published in November 2022, Oman's net emissions as of 2021 were over 90 Mt CO2, with five sectors—industry, oil and gas, power, transport, and buildings—contributing roughly 95% of the country's net emissions. Oman's emissions are expected to rise by 16% to 104 Mt CO_2e by 2050 if it doesn't take action now. Therefore, decreasing the dependency on the gas-fired power plant along with implementing the energy savings techniques will contribute to achieving the goal of net zero [3].

The Power System Expansion Plan emphasizes both short- and long-term objectives. The expansion strategy for the power system is predicated on meeting reliability standards. Loss of load probability satisfies the reliability requirements. It illustrates the danger of not having enough generation to satisfy the anticipated load demand. The three categories of "base load," "peak load," and "intermediate load" are used to forecast various sorts of loads. Base load, peak load, and intermediate loads can all be distinguished using load duration curves [4].

This paper aims to find energy-saving potential in the residential sector of Oman, focusing mainly on MIS. At the beginning, a survey done to capture the studies of energy savings potential from the residential sector. Using generation expansion planning software (WASP), an optimal long-term generation expansion plan would be created for 20 years. This optimization will be examined for base case and a case after assessing the energy saving from residential sector. For the two cases, environmental and externality costs will be calculated. Additionally, a comparison will be held between the two cases in terms of average Loss of Load Probability (LOLP) and the environmental cost savings.

2. Literature review

Estimating the system's running costs and dependability is crucial when designing a power system. It's crucial to model the system load and generation units properly in order to produce these calculations. Electrical load forecasting, generation planning, and electrical network planning make up power system planning [5].

This survey will provide essential studies of the possibilities for energy savings in the home sector. Paper [6] attempts to find a substitute for expanding current fossil power plants to meet Indonesia's rising electricity demand, through increasing electrical energy efficiency. The paper conducts a survey of 600 peoples from different seven cities exist in Indonesia in the period of November-2011 to January 2012. This survey was done to determine the characteristics and consumption of the appliances used inside homes. The outcome reveals that appliances with the highest potential for electrical energy savings include lights, televisions, refrigerators, and air conditioners. The findings of the survey were then used to launch energy-saving initiatives and prevent the building of additional power plants, lowering generation costs [6].

Another study [7] presents a survey that was done to assess the potential of energy savings in the residential sector in Thailand. In 2018, the entire country of Thailand underwent a questionnaire interview survey that included 7,192 households to determine how many different types of appliances were used. The extrapolation's energy model assumes that most of the residential electricity demand occurs at the local level. The outcome reveals that the household's total annual power consumption in 2018 was 35,624.37 GWh. By switching to more energy-efficient appliances, roughly 13.97% of power use, or 4,975.89 GWh or 2.39 MtCO2, might be decreased.

Research about the generation expansion conducted for the Cameron power system that will be included in the 2035 vision is provided in [5]. In this paper, many aspects were considered in the energy savings of the country, energy efficiency from the demand side, power losses, and environmental pollutants. It states that standardizing domestic appliances and using more energy-efficient equipment could result in up to 30% potential energy savings for the residential and end-user sectors.

These mentioned studies revels that the residential electricity consumptions play a significant role in the total amount of the consumed energy. Therefore, studying the potential of saving is needed to decrease the number of investments on building power plants. This study focuses on the generation expansion planning approach for determining the total avoided generation costs and environmental costs after lowering the energy consumption in the residential sector of Oman.

3. Methodology

To find the energy savings from residential consumption in the Sultanate, the following steps are conducted:

1. Using the base load forecast, the optimal generation mix is found for the 20-year period (2023–2042) at the least cost. This is called the base case. The load and generation data used were taken from Oman Power and Water Procurement Company's (OPWP) report [8].
2. From WASP, and after finding the optimal generation expansion plan, the following are found:
   a. The generation needed (addition) for the whole study period.
   b. Capital and operation costs.
   c. Reliability cost.
   d. Yearly environmental cost from energy data.
3. Using the percentage of energy consumption savings from the residential sector, the load forecast is modified (peak load) and entered into the WASP as another case (called the "Energy Savings Case"). The percentage was founded from [9-10] to be 25.2 percent from the houses demand from the total MIS demand.
4. Conduct the re-optimization for the energy-saving case using the same generation and reliability input data.
5. Perform step two for the energy-saving case.
6. Determine the avoided cost of generation by subtracting the base-case value from the value of the energy-saving case.
7. Assuming that the distribution transmission and distribution assets throughout the electricity system are almost equal to generation assets, we calculated the avoided transmission and distribution (T&D) capacity cost [11].

4. Planning model and data

4.1. WASP-IV Software and Model

The IAEA developed a program called WASP (Wien Automatic System Planning) [12] for assessing the generation expansion process. It was initially created and developed in the 1970s, but over time it has been improved and expanded to meet new demands and enable research on current concerns like ecological regulations, market restructuring, etc. When it comes to the lowest discounted overall expenses, the best option is chosen. The following expression is a representation of the cost function utilized by WASP; this cost function will use the entered generation data to evaluate:

$$B_j = \sum_{t=1}^{T} \left(\overline{I_{J,t}} - \overline{S_{J,t}} + \overline{L_{J,t}} + \overline{F_{J,t}} + \overline{M_{J,t}} + \overline{U_{J,t}} \right) \qquad 1$$

Where:

I Depreciable capital investment costs
S Salvage value of investment costs
L Non-depreciable capital investment costs
F Fuel costs
M the non-fuel operation and maintenance costs

U Not served energy cost

B_j The objective function

The bar above the symbols shows numbers that have been discounted to a base year or reference year using a specified discount rate.

While simultaneously addressing every constraint, WASP examines configurations from capacity expansions that would be able to fulfil demand in each year of the research period. The restrictions can be related to attaining a certain level of system reliability, fuel accessibility, building utilizing various technologies, or environmental contaminants [12].

There are seven modules in the WASP, summarized as follows:

- Module 1: LOADSYS (Load System Description)—Information on the power system's period peak loads and load duration curves is processed over the course of the study period.
- Module 2: FIXSYS (Fixed System Description): processing information on the current generation system, any planned additions or retirements, and any restrictions the user may have placed on environmental emissions, fuel availability, or the amount of electricity some plants may generate.
- Module 3: VARSYS (Variable System Description) analyzes data about the numerous generating units that should be taken into consideration as potential candidates for the generation system's expansion.
- Module 4: CONGEN (Configuration Generator) analyzes all potential year-to-year combinations of expansion candidate additions that meet specific input requirements and that, when combined with the fixed system, can meet the loads. Additionally, CONGEN determines the combined list of FIXSYS and VARSYS plants' basic economic loading order.
- Module 5: MERSIM (Merge and Simulate) calculates the associated production costs, energy not served, and system dependability for each configuration by considering all configurations proposed by CONGEN and operating the system using probabilistic simulation. Any restrictions placed on specific plant groups for their environmental emissions, fuel accessibility, or power generation are also considered during the process. Plants are sent so that all group constraints, maintenance needs, spinning reserve needs, and plant availability are met with the least amount of expense.
- Module 6: DYNPRO (Dynamic Programming Optimization), based on previously calculated operational expenses and input data on construction costs, energy not served costs, economic characteristics, and reliability criteria, determines the best expansion plan.
- Module 7: REPROBAT (Report Writer of WASP in a Batched Environment) creates a report summarizing the whole or partial outcomes for the predetermined expansion schedules and the optimal or nearly optimal power system expansion plan. On the file that can be used to display the WASP results graphically, some of the REPROBAT computations' results are also kept.

The first three modules can be executed independently in any order. The next three modules, modules 4, 5, and 6, are executed in order after the execution of modules 1, 2, and 3. The summary report is produced from the seventh module.

4.2. Generation Data

The generation expansion in this paper is commenced for MIS for the next 20 years starting from 2023 to 2042. Several power stations operate in MIS with different type and size. The majority of MIS generation is natural gas units, either open-cycle or combined-cycle units. More than 9200MW is available from these power station (year 2023) [8]. This study contains existing units, committed units (units that are expected to be commissioned and utilized in the near future), as well as retired and candidate ones. Candidate units are those used for the expansion process. The selection of the candidate units is based on their economic and technical features. In this study, six types of candidate units are considered, which are: OCGT, CCG1, CCG2, SOLAR, and WDUQ. Table 1 lists the parameters of the five candidate plants.

Table 1 Candidate Units Parameters

Name	OCGT	CCG1	CCG2	SOLAR	WDUQ
Min. Load (MW)	100	222	175	100	50
Capacity (MW)	100	700	430	100	50
Heat Rate (kcal/kWh)	2520	2521	2521	3000	2000
Avg. Incr. Heat Rate (kcal/kWh)	2520	1266	946	3000	2000
SPR %	0	9	9	0	0
FOR %	3	2.5	2.5	62	70
Days scheduled per years	34	27	27	10	10
O&M Fix ($/kW-month)	1.46	0.92	0.83	1.95	3.3
O&M Var ($/MWh)	3.5	3.5	2	0	0

4.3. Load Data

The energy calculation in WASP involves the load duration curve (LDC). A normalized LDC is obtained from actual hourly load data for the summer and winter periods of a complete year. The expected peak demand for 2023 is 7640 MW, while 12926 MW is expected for 2042, as per the data provided by OPWP [8]. The represented megawatt includes all system demand as well as system losses (transmission and distribution losses). Peak demands for the years 2023–2042, along with the residential accounts, which are considered to be 45.2% as per the APSR annual report, are shown in Table 2. Reference [10] states that 25.2% saving from the residential sector can be achieved, so that the reduced residential demand is shown in the table. Then, the modified peaks for the energy-saving case listed in the last column showed a percentage drop of about 11.4%. These values were used for the energy savings case in the WASP optimization study. Figure 1 illustrates the peak load data for both cases that are used in this study.

Table 2 Load Data for Both Cases

year	Peak load for Base Case (MW)	Residential load for Base case (MW)	Residential load for Energy Saving case (MW)	Peak load for Energy Saving Case (MW)
2023	7640	3453	2583	6770
2024	7960	3598	2691	7053
2025	8020	3625	2712	7106
2026	8200	3706	2772	7266
2027	8370	3783	2830	7417
2028	8546	3863	2889	7573
2029	8802	3979	2976	7799
2030	9066	4098	3065	8033
2031	9338	4221	3157	8274
2032	9618	4347	3252	8522
2033	9907	4478	3350	8779
2034	10204	4612	3450	9042
2035	10510	4751	3553	9313
2036	10828	4894	3661	9595
2037	11150	5040	3770	9880
2038	11485	5191	3883	10177
2039	11829	5347	3999	10482
2040	12184	5507	4119	10796
2041	12550	5673	4243	11121
2042	12926	5843	4370	11454

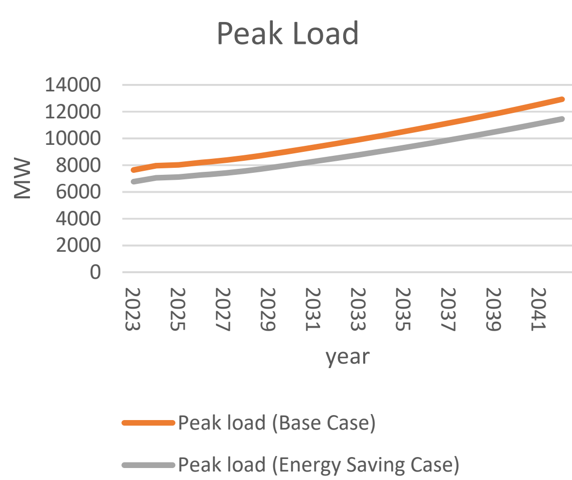

Figure 1 Peak Load for Both Case

4.4. Externality costs

The conventional power plant increase the emissions of some gasses that considered as an environmental concern. The most significant once are (CO_2, SO_2, NO_x and some particulates). The amount of kg of the CO_2, SO_2, NO_x and some particulates produced per MWh from the gas-fired and the combined cycle plant are listed in Table 3 [13]. Table 4 shows the externality costs for the four pollutants that utilized in this study.

Table 3 Factors of Emissions

Type	CO_2 (kg/MWh)	SO_2 (kg/MWh)	NO_x (kg/MWh)	Particulates (kg/MWh)
OC (Gas-fired)	550	0.0998	1.343	0.0635
Combined Cycle	367	0.0665	0.895	0.042

Table 4 Pollutants Externality Cost

Pollutants	Externality Cost in $/kg
CO_2	0.05
SO_2	7
NO_x	5.5
Particulates	33

The emission in kg and the emission cost are calculated by the equations below:

$$\text{Externality in kg} = \text{Discounted energy of study period (MWh)} \times \text{Emission factor (kg/MWh)} \quad (2)$$

$$\text{Externality cost (\$)} = \text{Emission (kg)} \times \text{Externality cost (\$/kg)} \quad (3)$$

4.5. Assumptions and Constraints

The study assumptions summarized as follows:

- The system has enough capacity to meet both the necessary demand and the load growth that occurs annually.
- To handle any unexpected, unforeseen plant outages, the system has adequate reserve margin.
- The candidate plants for expansion should be most suitable for Omani power sector.
- The expansion plans should be least-cost and have minimum impact on the environment.
- The study relies on the energy saving findings in residential sector of Oman of reference [10].

The study constraints summarized as follows:

- Minimum reserve margin should be at-least 5%.
- The expected Loss of Load expectation is specified to be one day per year (less than 0.28% probability).

The study considers the selection and mix of candidate plants that will be chosen and the timing at which they will be integrated into the system. The study does not take into account the transmission constraints in the selection of candidate plants. The chosen plants' potential future fuel availability is not taken into account in the study.

5. Results

Table 5 summarizes the results obtained from the WASP-IV for the optimization of both scenarios.
It shows the amount of capacity added to the system in GW, the cost of the generation plan in billions of dollars,

followed by the T&D cost, which is assumed to be similar to the generation plan cost with the assumption that total T&D assets are roughly equal to generation assets [13]. In addition, the environmental cost is calculated using the equation for externality cost and then discounted to the year 2023 with a discount rate of 8%. The next three columns show the total cost, avoided cost, and avoided environmental cost. The LOLP for both cases is shown in the last column. Using WASP IV to simulate, the base case optimization findings show that the cost of the entire system expansion will be 49.29 billion US dollars, with a total of 15.69 GW added and an average loss of load probability (LOLP) of 0.2589%. Results revels that the total cost decreased for the case of energy saving from the residential sector, as well as the amount of the capacity addition dropped. The avoided cost is calculated by taking the difference between the base case and the energy-saving case. A 5.632 billion of dollars are saved for the second case, where 1.399 billion saved for the environmental cost. This is due to the fact that the proposed savings described in [10] in residential sector significantly reduces system load, resulting in considerable savings in terms of avoided costs.

Table 5 Summary Results

Scenarios	Base Case	Energy Saving Case
Capacity Addition (GW)	15.69	14.19
Generation Plan Cost (Billion $)	19.18	17.06
T&D Cost (Billion $)	19.18	17.06
Environmental Cost (Billion $)	10.93	9.53
Total Cost (Billion $)	49.29	43.66
Avoided Cost (Billion $)	-	5.632
Avoided Environmental Cost (Billion $)	-	1.399

6. Conclusion

Researchers are looking into ways to limit the development of new power plants in response to the significant increase in Oman's load in recent years. Reducing electricity use during peak hours will provide the system with more flexibility and reduce the need for new generation units to be added. In particular, the MIS load in Oman's residential sector is the focus of this paper's research. The statistics on demand consumed are often included in the Annual Report distributed by the APSR. According to this, the domestic consumption for 2021 will account for roughly 45.2%. A survey of articles from various publications that highlight the important role that energy savings in the residential sector play is conducted.

The optimization generation expansion plan is carried out using the WASP-IV software over a 20-year timeframe. Another scenario is investigated: a consumption decrease of 25.2% in the residential sector. The study's assumptions and restrictions are discussed along with the methodology. The findings demonstrate a significant reduction in the overall generating cost and environmental cost for the energy savings case compared with the base case, as well as the LOLP percentage. A total of 5.632 and 1.399 billion US dollars in costs were saved overall and, on the environment, respectively.

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