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Integrated renewable energy and load management strategies in power systems

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ABSTRACT

The introduction of the renewable energy resources in the load management problem as part of smart grid initiatives requires further investigation and modifications to the load management formulation. In this regard, an innovative renewable energy storage scheme is introduced and investigated in this paper. In the approach followed in this paper, a portion of the demand energy is supplied from either solar panels or wind-driven energy schemes, which add to the green energy component of the load management scheme. The renewable energy- load management technology employed in this paper, while is being applied to the Hail bulk electricity area in Saudi Arabia, is general and can be applied quite as well to other bulk areas in the electricity system. The results for the application Scenario considered in this paper shows a maximum attainable annual profit of 14.7% can be achieved at off-peak valley filling designed capacity of 800 MWh with assumed energy reallocation efficiency of the load-management system of 50%.

1. Introduction

Load management strategies currently receive an overwhelming attention in the electricity sectors worldwide and, particularly, in the Kingdom of Saudi Arabia. This interest stems from a pressing need to match the ever-increasing future demand on power and energy with the envisaged generation capabilities. In this regard, an emphasis is given to the reduction and/or shifting the peak loads in the overall demand pattern in order to limit the actual generation facilities required to supply the peak load and to improve the overall energy consumption pattern.

The introduction of the renewable energy resources in the load management problem as part of smart grid initiatives requires further investigation and modifications to the load management formulation. In this regard, an innovative renewable energy storage scheme is introduced and investigated in this paper. The load management scheme is similar to the pumping storage systems, but incorporates renewable energy resources and, therefore, is more suited to the operating environment in Saudi Arabia, in which water is relatively scarce. A portion of the off-peak valley filling energy is supplied from solar and wind-driven generators, which adds to the green energy component of the scheme.

A number of publications have appeared in the literature dealing with the general problems of load management and renewable energy resources. While most published techniques are theoretical with limited domain of practical applications, they provide adequate background on the subject. References (Bellarmine, 2000; El-Kady, 2007) provide basic background on the problem of load management and peak reduction in electric power systems and the associated process of shifting the peak loads in the overall demand pattern in order to limit the actual generation facilities required to supply the peak load. Techniques and approaches for molding and utilizing the renewable energy resources in the electricity grid were presented in references (Baring-Gould et al., 2003; El-Kady et al., 2012). References (Rehman et al., 2003; Schillings et al., 2004) contain useful renewable energy data and information relating to Saudi Arabia and its operating environment. The use of advanced modeling methodologies and simulation techniques for analyzing load management problems is outlined in references (Alvarez et al., 1992; El-Kady et al., 2012). The impact of using load management in power systems and the associated performance assessment are outlined in references (Sadineni et al., 2012; Huang and Billinton, 2011). Reference (Bouhouras et al., 2010) presented some practical applications involving load management initiatives by the power companies. Other issues relating to load

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management and renewable energy resource integration are discussed in references (Falahati et al., 2012; Park et al., 2010). Some modern technologies relating to load management and energy conservation programs as well as associated electricity market strategies are documented in in references (El-Kady et al., 1999; Al-Saud et al., 1999). Specific data and information as well as application and implementation of solar energy technologies in Saudi Arabia are documented in in references (Mohandes and Rehman, 2010). Specific data and information on renewable resources in Saudi Arabia are documented in references (Goulding and Neil, 2009). Specific data and information as well as application and implementation of wind energy technologies in Saudi Arabia are documented in in references (Aljarboua, 2009; Elhadidy and Shaahid, 2007; Obaid, 2011; Rehman et al., 2003). The main purpose of the present research work is to develop an innovative integrated renewable energy and load management methodology for continually evolving electric power systems. The new methodology suits a wide range of applications for intelligent demand management and renewable energy resource utilization in electric power systems incorporating smart grids concepts. The proposed scheme uses intelligent sensitivity analysis to guide the optimally designed load management strategies in order to incorporated available primary renewable energy resources.

The approach introduced in this paper is particularly useful for the operating environment of Saudi Arabia where renewable energy (particularly solar and wind energies) is abundant and the peak demand is hardly covered by the available generation resources. Practical applications will be conducted as part of the paper, which use a portion of the Saudi electricity grid to demonstrate the implementation of the proposed scheme.

The proposed methodology of load management is based on the utility-initiated activities to alter the shape of the overall system demand (in MW or GW) versus time curve. Technically speaking, the area under the system load curve, which represents the total energy (in GWh or TWh) consumption over the designated time period, is not of a primary concern to the term "load management". Load management is undertaken by power utilities to alter the load shape in order to achieve a better balance (matching) between the customer's cyclic demand and the utility's current and planned generating as well as transmission and distribution resources. Also, the proposed scheme uses intelligent sensitivity analysis to guide the optimally designed load management strategies in order to incorporated available primary renewable energy resources.

2. Problem formulation

2.1. Load management scheme

In the approach followed in this paper, a portion of the demand energy is supplied from either solar panels or wind-driven energy schemes, which add to the green energy component of the load management scheme. The renewable energy- load management technology employed in this paper, while is being applied to the Hail bulk electricity area in Saudi Arabia, is general and can be applied quite as well to other bulk areas in the electricity system.

A load management scheme, as depicted in Fig. 1 is used which aims at reducing the peak load during the off-peak period by any conventional demand management technology and, then, using the stored potential energy to generate electricity during the following peak period of the demand pattern and, therefore, replacing the actual generation that would otherwise have to be used from the power plants. The load management analysis employs a set of advanced simulation modules, which maps the peak/off-peak demand pattern of the system over a period of time and produces a projected estimate of the benefits.

In essence, load management is undertaken by power utilities to alter the load shape in order to achieve a better balance (matching) between the customer's cycle demand and the utilities' current and planned generating as well as transmission and distribution resources.

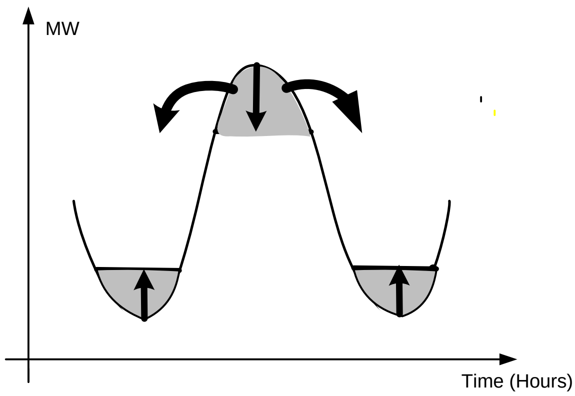

Fig. 1: Illustration of peak shifting and valley filling

In the present setup, load flattening is the prime objective of the load management scheme. Load flattening scheme transfers loads that would occur on-peak to off-peak periods, thus combining peak clipping and valley filling. This can be achieved by implementing two distinctive load management functions, namely peak clipping and valley filling. These two functions are described as follows:

2.1.1. Peak clipping

Peak clipping aims at reducing the peak demand on a utility system by decreasing the on-peak electricity consumption. Let P(t) denote the system load (MW) as a function of time t (hours), between 0 and T. The total saving in energy costs as a result of peak clipping, to a new "clipped" power (MW) of Pc, is given by

$$CE_{sav} = C_e[\int_0^T Q(t) \cdot d(t)] \quad (1)$$

where Ce is the average cost of energy in Saudi Riyals per MWh (SR/MWh), and the difference function Q(t) is given by

$$Q(t) = \begin{cases} 0 & for\ P(t) \leq P_C \\ \{P\ (t) - P_C\} & for\ P(t) > P_C \end{cases} \quad (2)$$

In addition to the saving in energy costs as a result of peak clipping, there is also a saving associated with reducing system capacity requirement. The capacity-type is given by

$$CP_{sav} = C_P[Max\{P(t) - P_C] \quad (3)$$

where Cp is the cost capacity (SR/MW).

2.1.2. Valley filling

Valley filling is designed to increase load during off-peak periods. Such action is appropriate to undertake when the incremental cost of serving this load is lower than the average cost of electricity. Let P(t) denote the system load (MW) as a function of time t (hours), between 0 and T.

The total energy (MWh) added to increase the valley portion of the load curve to a new power level of Pv (MW) is given by

$$E_{add} = [\int_0^T R(t) \cdot dt] \quad (4)$$

where R(t) is given by

$$R(t) = \begin{cases} 0 & for\ P_V \leq P(t) \\ \{P_V - P(t) & for\ P_V > P(t) \end{cases} \quad (5)$$

In the present application of load flattening, the efficiency of the energy reallocation (shift from/to peak/off-peak) process plays an important role in assessing the overall merits of the load management scheme employed.

Consider the load-flattening scheme illustrated in Fig. 2 in which the peak energy E1 is to be reallocated to the two valley portions as E2a and E2b.

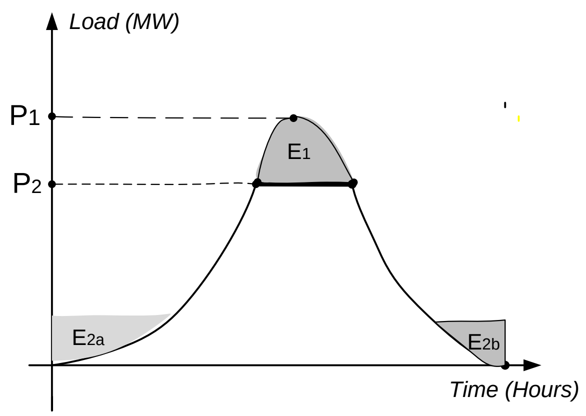

Fig. 2: Illustration of load flattening

The energy reallocation process is assumed to take place with certain efficiency. The load flattening action can be simulated by a set of expressions and relationships. The amount of shifted energy is given by

$$E_{2a} + E_{2b} = \frac{E_1}{\zeta} \quad (Utility\ Model) \quad (6)$$

$$E_{2a} + E_{2b} = E_1 \cdot \zeta \quad (Customer\ Model) \quad (7)$$

In the above two expressions, distinction is made between the case where the utility picks up the losses in energy reallocation process (utility model) and the case where the customer bears these losses (customer model). In both cases, ζ denotes the efficiency of energy shift process. The capital costs of generating capacity according to the original (case 1) and the shifted (case 2) curves are:

$$\mathrm{Cos}\,t_1 = C_P \cdot P_1 \quad (8)$$

$$\mathrm{Cos}\,t_2 = C_P \cdot P_2 \quad (9)$$

where Cp is the total cost of capacity (SR/MW). The revenue in each case (SR) can be written as:

$$Re\ v_1 = C_e[E_0 + E_1] \cdot (8760 \cdot n) \quad (10)$$

$$Re\ v_2 = C_e[E_0 + E_{2a} + E_{2b}] \cdot (8760 \cdot n) \quad (11)$$

where Ce is the cost of the unit of energy in (SR/MWH) and n is the number of years during the study period.

We now define the two functions F1 and F2 as:

$$F_1 = Re\ v_1 - \mathrm{Cos}\,t_1 \quad (12)$$

$$F_2 = Re\ v_2 - \mathrm{Cos}\,t_2 \quad (13)$$

where F1 and F2 denote the net benefit (revenue – cost) in each case (SR).

Hence, the difference between the two cases could be written as:

$$\mathrm{f} = \mathrm{F}_2 - \mathrm{F}_1 \quad (14)$$

which, according to the simple model considered, is an indicative of the overall merit of carrying out the load management program. Our goal is to find the optimal clipping point (PC = P2) at which the function f will reach its maximum positive value for different values of energy shift efficiency. At this point (PC) the high economical clipping benefit from the scheme will be achieved.

2.2. Simulation of renewable resources

When renewable energy resources are introduced in the load management problem, the load P(t) in the previous equations is modified as

$$\mathrm{P(t)} = \mathrm{P_O(t)} - \mathrm{P_r(t)} \quad (15)$$

where $P_o(t)$ denotes the original load curve and $P_r(t)$ represents the renewable resources available. In this regard, $P_r(t)$ has two distinct components, namely the solar energy resources component and the wind energy resources component. That is:

$$\mathrm{P_r(t)} = \mathrm{P_s(t)} + \mathrm{P_w(t)} \quad (16)$$

where Ps(t) denotes the solar energy time pattern and Pw(t) denotes the wind energy time pattern.

2.3. Cost benefit assessment

2.3.1. Cost components

The costs associated with the developed integrated load management and renewable resources system is calculated on an annual levelized basis {MSR/Year} using the associated capital recovery factors (for a given life span of the facilities). The costs include the following key components:

1) Energy and capacity dependent costs of the load management system establishment.
2) Operating costs associated with the load management system.
3) Other indirect costs associated with the reduced peak impact (reduced peak energy sales).
4) Capital costs associated with the establishment of the renewable (solar and wind) energy resources.
5) Operating costs associated with operating and maintaining the renewable (solar and wind) energy resources.

2.3.2. Savings

The savings associated with the developed integrated load management and renewable resources systems are also calculated on an annual levelized basis {MSR/Year} using the associated capital recovery factors (for a given life span of the facilities). The savings include the following key components:

1) Clipped (saved) peak generation replacement capacity cost.
2) Reduced peak operation cost due to load management.
3) Increased off-peak indirect energy sales due to load management.
4) Clipped peak generation replacement capacity cost saving due to renewable resources.
5) Reduced peak operation cost due to renewable resources.

3. Practical application

A practical application case scenario, based on a scaled 2014 hourly load records of Hail electricity demand pattern (projected from the actual Hail peak demand at a previous year), was considered to demonstrate the theoretical and analytical developments of this paper.

3.1. Application data assumptions

As outlined earlier in this paper, the application of the analytical formulation and cost analysis model of Section 2 for the integrated load management and renewable resources problem was conducted based on a set of assumptions. The following key assumptions were made in the present simulation based assessment study. The following parameter values are assumed based on the data and information available:

1) Off-peak tariff = 10.3 H/kWh
Definition: Tariff charged to consumer during off-peak hours.
2) Peak tariff = 13.4 H/kWh
Definition: Tariff charged to consumer during peak hours.
3) Fixed Capital Energy-Dependent Cost of LM System = 0.1 M$/MWh
Definition: Fixed Capital Cost component of the load management system, which depends on the maximum installed energy capacity of the system. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}.
4) Constant Cost of Load-Management Installation System = 20 MSR
Definition: Capital cost component of the load management system which is constant.
5) Fixed Capital Power-Dependent Cost of LM System = 1 M$/MW
Definition: Fixed Capital Cost component of the load management system, which depends on the installed capacity of the load management scheme. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}.
6) Operation and Maintenance Energy-Dependent Cost of LM System = 0.00006 M$/MWh
Definition: Operation and Maintenance Cost component of the load management system, which depends on the actually processed off-peak energy of the system.
7) Power-Dependent Linear Cost of Peak-Generation Shifted = 3 M$/MW (Scenarios #1 and #3) and 5 (Scenarios #2 and #4) M$/MW. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}
Definition: Replacement cost per MW of the peak-generation shifted by the load management system.
8) Energy-Dependent Linear Cost of Peak-Generation Shifted = 0.000030 M$/MWh
Definition: Replacement cost per MWh of the peak-generation shifted by the load management system.
9) Number of Years for Cost-Depreciation = 20 Years
Definition: Number of life years of the load management system.
10) Energy Reallocation Efficiency of Load-Management System = 50% (Scenarios #1 and #3) and 40% (Scenarios #2 and #4)
Definition: Efficiency of peak-shifting process of the load-management system.
11) Interest Rate for Capital Recovery Factor Calculation = 5% / year
Definition: Interest rate charged for the borrowed capital of the load management system.
12) Maximum Power Capacity of Solar Resource = 200 MW (Scenarios #1 and #3) and 100 MW (Scenarios #2 and #4)

Definition: Maximum installed capacity (in MW) of the solar renewable resource system.

13) Fixed Capital Energy-Dependent Cost of Solar Resource = 0 M$/MWh

Definition: Fixed Capital Cost component of the installed solar renewable resource system, which depends on the maximum installed energy capacity of the system. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}

14) Fixed Capital Power-Dependent Cost of Solar Resource = 10 M$/MW (Scenario #1), 8 M$/MW (Scenario #2), 9.375 M$/MW (Scenario #3) and 37.5 M$/MW (Scenario #4)

Definition: Fixed Capital Cost component of the installed solar renewable resource system, which depends on the installed capacity of the load management scheme. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}

15) Operation and Maintenance Energy-Dependent Cost of Solar Resource = 0 M$/MWh

Definition: Operation and Maintenance Cost component of the installed solar renewable resource system, which depends on the actually processed off-peak energy of the system.

16) Maximum Power Capacity of Wind Resource = 100 MW (Scenarios #1 and #3) and 50 MW (Scenarios #2 and #4)

Definition: Maximum installed capacity (in MW) of the wind renewable resource system

17) Fixed Capital Energy-Dependent Cost of Wind Resource = 0.00000108 M$/MWh (Scenarios #1 and #2) and 0.00000405 M$/MWh (Scenarios #3 and #4).

Definition: Fixed Capital Cost component of the installed wind renewable resource system, which depends on the maximum installed energy capacity of the system. This cost is phased out over the system life-span (in years, 365.25 days per-year.

18) Fixed Capital Power-Dependent Cost of Wind Resource = 1.90573 M$/MW (Scenarios #1 and #2) and 7.1465 M$/MW (Scenarios #3 and #4)

Definition: Fixed Capital Cost component of the installed wind renewable resource system, which depends on the installed capacity of the load management scheme. This cost is phased out over the life-span of the system (in years, 365.25 days per-year}

19) Operation and Maintenance Energy-Dependent Cost of Wind Resource = 0.000007 M$/MWh (Scenarios #1 and #2) and 0.00002625 M$/MWh (Scenarios #3 and #4)

Definition: Operation and Maintenance Cost component of the installed wind renewable resource system, which depends on the actually processed off-peak energy of the system.

20) Government Subsidy for Renewable Energy Resources = 90% (Scenarios #1, #3 and #4) and 70% (Scenario #2)

Definition: Assumed percentage subsidy/refund by government to offset the relatively very high cost of renewable resources (as compared with conventional low-priced oil based generation) as a means to encourage green energy and promote renewable resource technologies.

Furthermore, the following simulation execution settings were selected for the purpose of conducting the assessment study:

Simulation Module: Advanced simulation of integrated load-management / renewable resources business strategies.
Technology: Demand management with renewable energy generation tapped into the power grid.
Simulation Sampling: Hour by hour for one year (continuous operation)
Demand profile: Saudi Arabia – Hail Region (scaled 2014 Hail peak demand)
Operation Period: One year
Life Span of Facilities: 20 years
Investment Mode: Utility Owned System
Electricity Market Model: Semi open
Cost Coefficients: User Supplied
Use of Capital Recovery Factor: Yes
Capital Borrowing Mode: Subsidized for renewable component only
Incorporation of Hybrid Renewable Resources: Yes

3.2. Processed demand profiles

One set of processed demand profiles (for various days of the year and for different off-peak valley filling capacity scenarios of the load management system) were produced for the integrated load management and renewable resources system applied to the Hail electricity system. The demand profile pertains to the application scenario presented in this paper in which the energy reallocation efficiency of load-management system is 50% and the maximum power capacities of the solar and wind resources are assumed to be 200 MW and 100 MW, respectively.

Fig. 3 shows an example of the processed demand profile of Hail electricity system for a winter day (January 4th) with an off-peak valley filling capacity of 800 MWh. On the other hand, Fig. 4 shows an example of the processed demand profiles of Hail electricity system for a spring day (March 13th) with an off-peak valley filling capacity of 800 MWh.

3.3. Scenario application results

In this application scenario of the integrated load management and renewable resources system to Hail electricity system, the following particular data assumptions are applied:

Power-Dependent Linear Cost of Peak-Generation Shifted = 3 M$/MW
Energy Reallocation Efficiency of Load-Management System = 50%
Maximum Power Capacity of Solar Resource = 200 MW
Fixed Capital Energy-Dependent Cost of Solar Resource = 0 M$/MWh

Fixed Capital Power-Dependent Cost of Solar Resource = 10 M$/MW

Operation and Maintenance Cost of Solar Resource = 0 M$/MWh

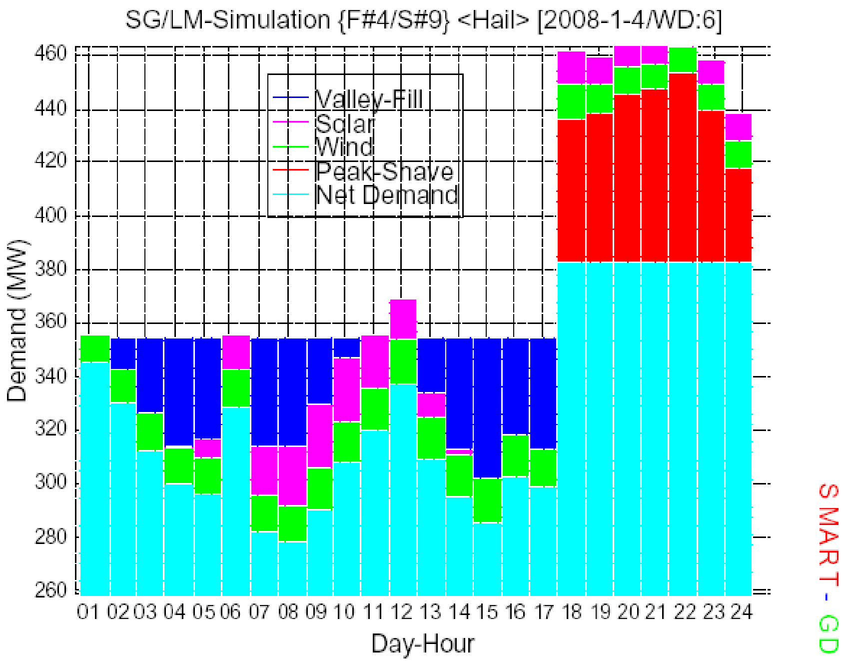

Fig. 3: Sample of processed demand profiles for Hail electricity system on January 4th: Off-peak valley filling capacity of 800 MWh (Energy reallocation efficiency = 50%, Maximum power capacities of the solar and wind resources = 200 MW and 100 MW, respectively)

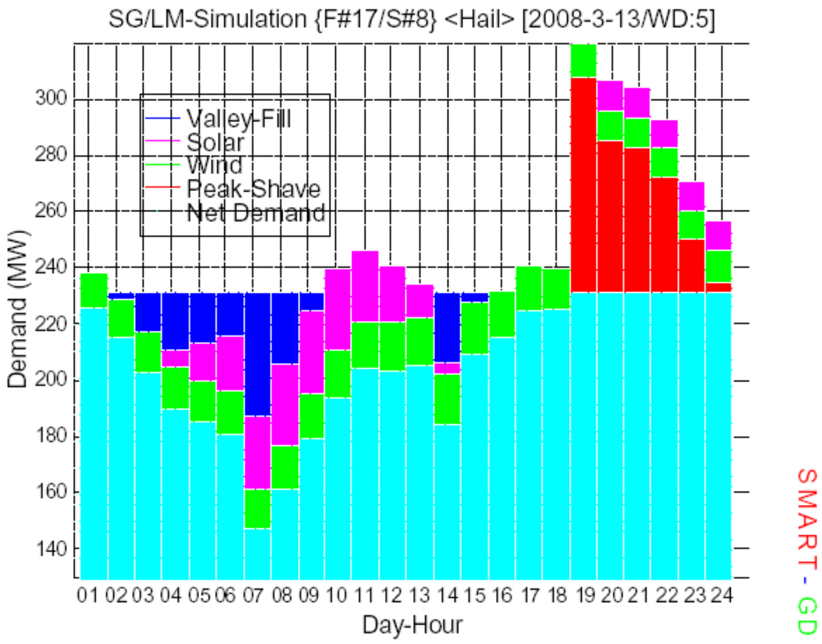

Fig. 4: Sample of processed demand profiles for Hail electricity system on March: Off-peak valley filling capacity of 800 MWh (Energy reallocation efficiency = 40%, Maximum power capacities of the solar and wind resources = 100 MW and 50 MW, respectively)

Maximum Power Capacity of Wind Resource = 100 MW
Fixed Capital Energy-Dependent Cost of Wind Resource = 0.00000108 M$/MWh
Fixed Capital Power-Dependent Cost of Wind Resource = 1.90573
Operation and Maintenance Cost of Wind Resource = 0.000007 M$/MWh
Government Subsidy for Renewable Energy Resources = 90%

The simulation modules were successfully accessed and executed to calculate and display the processed results for this application scenario. In this regard, an hour-by-hour analysis was conducted for each daily demand pattern to evaluate – for each identified off-peak filling energy level – various costs and savings components as outlined in Section 2 of this paper.

Fig. 5 summarizes the results obtained while Figs. 5 and 6 depict the simulation generated sensitivity graphs, which are useful in revealing the relative impacts on various cost and saving components due to variations in the designed value of off-peak valley filling capacity of the load management system.

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Advanced Simulation of Smart-Grid Load Management ..... Module #3 Version #2/9
{Bulk Electric Power System Application Scenarios} .... <....................>
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SEC LM-Study {Eff=50%} {PkR=1.2} {SmR=1.5} <S50%-1.2/1.5> [File: LRUH1]  [OR5]
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1      400.0        34.9      53.3      39.4      59.1      10.8
2      450.0        37.9      56.3      43.2      62.9      11.7
3      500.0        40.9      59.3      46.9      66.6      12.4
4      550.0        43.7      62.1      50.2      69.9      12.6
5      600.0        45.7      64.2      52.7      72.4      12.8
6      650.0        47.5      65.9      54.8      74.4      13.0
7      700.0        48.6      67.0      56.3      76.0      13.5
8      750.0        49.4      67.8      57.7      77.4      14.1
9      800.0        50.3      68.7      59.1      78.8      14.7
10     850.0        50.9      69.3      59.4      79.1      14.1
11     900.0        51.4      69.9      59.6      79.3      13.5
12     950.0        51.9      70.3      59.6      79.3      12.8
13     1000.0       52.3      70.7      59.6      79.3      12.1
14     1050.0       52.7      71.2      59.7      79.3      11.5
==============================================================================
Column Definitions:
01. {S-#}    Sequential Load Management Scenario #
02. {SEo}    Specified Capacity for Off-Peak Filling Energy of LM-System (MW)
03. {C-LMS}  Total Smart-Grid Load-Management System Cost {M$}
04. {C-TOT}  Gross Smart-Grid Subsidized LM/Renewable System Cost {M$}
05. {S-LMS}  Total Smart-Grid Load-Management System Saving {M$}
06. {S-TOT}  Gross Smart-Grid LM/Renewable System Saving {M$}
07. {%-PFT}  Percentage LM/Renewable System Profitability {%}
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Fig. 5: Simulation results for application scenario (overall integrated load management + renewable system results)

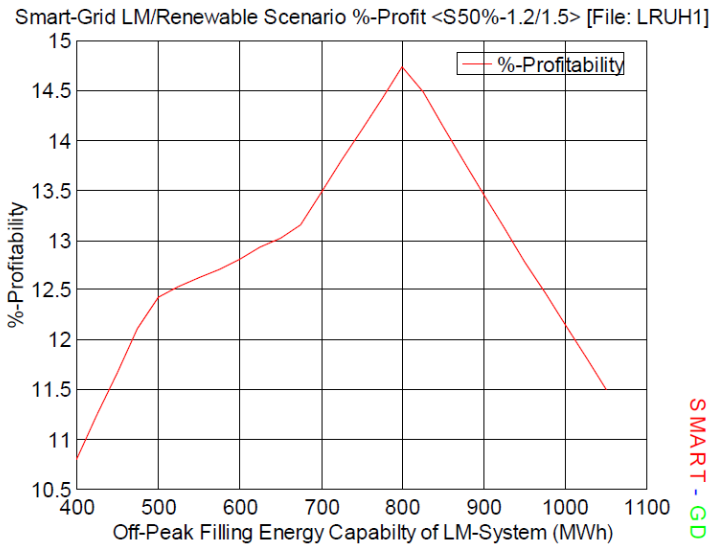

Fig. 6: Application Scenario: Sensitivity results for the integrated load management/renewable system cost-benefit results

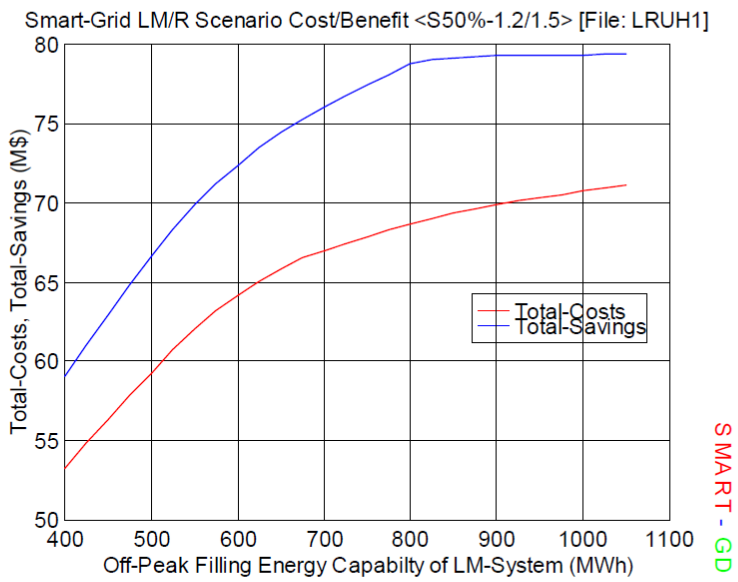

Fig. 7: Application Scenario: Sensitivity results for the integrated load management/renewable system overall profitability

4. Conclusion

It is important at the start to emphasize that the findings and conclusions from the undertaken study are based on the data and assumptions made as outlined in this paper. For example, the study calculations were based on the scaled 2014 peak demand pattern for the Hail Area. Also, the cost and saving coefficients as well as the rated capacity of the renewable energy resources were all assumed for illustration purposes in order to demonstrate the theoretical and analytical developments of this paper and to show the usefulness and applicability of the integrated load management and renewable resources system.

Although the study findings and conclusions may, of course, change if some or all of the assumptions are changed, the analytical model and computational scheme are general and can be applied to any electricity system under any assumed design and operation data.

The following key findings are deduced from the simulation based cost-benefit assessment conducted in the paper for the four application scenarios considered in the present study:

1. The maximum attainable profit for the application scenario was 14.7%, which occurred at off-peak valley filling designed capacity of 800 MWh.
2. The sensitivity analysis conducted in the present study represents a unique and powerful feature of this paper. The simulation generated sensitivity graphs are useful in revealing the relative impacts on various cost and saving components due to variations in the designed value of off-peak valley filling capacity of the load management system. In this respect, it noted that both total costs and total savings for all application scenarios increase rapidly at lower values of off-peak valley filling capacity and, then, tend to saturate at relatively higher off-peak valley filling capacity values when the demand pattern becomes almost flat with all available off-peak energy being utilized and moved to offset the peak portion of the daily load cycle. For example, in the application scenario considered in this paper, the total cost of the integrated load management and renewable resources system increases by 13.7 M$ (form 53.3 M$ to 67.0 M$) as the designed off-peak valley filling capacity increases by 300 MWh (from 400 MWh to 700 MWh). However, the same increase of 300 MWh in the designed off-peak valley filling capacity (from 700 MWh to 1000 MWh) would result in an increase of only 3.7 M$ in total cost (form 67.0 M$ to 70.7 M$).

List of symbols

Ce	Average cost of energy (SR/MWh)
Cp	Average cost of capacity (SR/MW)
CEsav	Total saving in energy costs
Cost1 (original)	Capital cost of generating capacity
Cost2 (peak-shifting)	Capital cost of generating capacity
CPsav	Total saving in capacity costs
Q(t)	Difference function between P(t) and Pc
E1	Peak energy to be reallocated
E2i	Valley energy portion (i)
Eadd	Total energy (MWh) added to increase valley portion of load curve
F1	Net benefit (revenue – cost) associated with original case
F2	Net benefit (revenue – cost) associated with peak-shifting case
n	Number of years (life span of facilities)
P(t)	Net system load (MW) as a function of time t (hours)
Pc	New “clipped” power (MW)
Po(t)	Original load curve before integration of renewable energy resources (MW)
Pr(t)	Time pattern of renewable energy resources available (MW)
Pv	New power level (MW)
Q(t)	Difference function between P(t) abd Pc
R(t)	Difference function between Pv and P(t)
Rev1	Revenue (SR) associated with original case
Rev2	Revenue (SR) associated with peak-shifting case
t	Time (hours)
ζ	Efficiency of energy shift process

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