

Review

Impacts of Demand-Side Management on Electrical Power Systems: A Review

Hussein Jumma Jabir ^{1,2} , Jiashen Teh ^{1,*} , Dahaman Ishak ¹ and Hamza Abunima ¹

¹ School of Electrical and Electronic Engineering, Universiti Sains Malaysia (USM), Nibong Tebal 14300, Malaysia; hjjahmn@gmail.com (H.J.J.); dahaman@usm.my (D.I.); habunima@gmail.com (H.A.)

² Inspector General Office, Ministry of Water Resources, Filastin 10046, Iraq

* Correspondence: jiashenteh@usm.my; Tel.: +60-4-599-6016

Received: 5 March 2018; Accepted: 16 April 2018; Published: 25 April 2018



Abstract: Electricity demand has grown over the past few years and will continue to grow in the future. The increase in electricity demand is mainly due to industrialization and the shift from a conventional to a smart-grid paradigm. The number of microgrids, renewable energy sources, plug-in electric vehicles and energy storage systems have also risen in recent years. As a result, future electricity grids have to be revamped and adapt to increasing load levels. Thus, new complications associated with future electrical power systems and technologies must be considered. Demand-side management (DSM) programs offer promising solutions to these issues and can considerably improve the reliability and financial performances of electrical power systems. This paper presents a review of various initiatives, techniques, impacts and recent developments of the DSM of electrical power systems. The potential benefits derived by implementing DSM in electrical power networks are presented. An extensive literature survey on the impacts of DSM on the reliability of electrical power systems is also provided for the first time. The research gaps within the broad field of DSM are also identified to provide directions for future work.

Keywords: reliability of electrical power systems; demand-side management; demand response; load management

1. Introduction

Modern electrical power systems must meet constantly changing power consumption requirements with a satisfactory level of reliability, environmental friendliness and quality [1]. Nevertheless, meeting these challenges has become progressively difficult owing to the increase in electricity demands caused by population and industrial growth. The International Energy Agency estimated that the global electricity demand in 2030 will be more than 50% higher than that in the present [2], for example, due to the massive implantation of the electric vehicle [3]. In addition to this issue, the infrastructure investments required to support the growing global electricity demand will be massive because ageing power system components will have to be replaced. Thus, the usual practices aimed at balancing electricity supply and demand have to be examined closely. Electricity saved is worth more than electricity generated [4]. For example, after accounting for transmission and distribution along line losses, one unit of electricity saved at the consumer side is worth 10% more of the unit saved at the generator side.

In modern and deregulated power systems, distribution companies bid for electricity prices to maximize their profits. Electricity prices fluctuate in accordance with real-time electricity demands. Specifically, electricity prices increase as demand rises and vice versa. Prudent power system management is necessary to ensure the constant supply and trading of electricity. The management of power systems is classified into supply-side management and demand-side management (DSM).

Both strategies are useful for mitigating contingencies, increasing network loading capacity and reducing peak loads.

Supply-side management aims to increase the operational efficiency of electricity generation, transmission and distribution [5]. The benefits of supply-side management include: (1) ensuring efficient energy production at the minimum economic cost and thus maximizing consumer value; (2) satisfying electricity demand without the addition of unnecessary infrastructure investments; and (3) minimizing environmental impacts through the efficient operation of power system assets. Nonetheless, supply-side management is affected by the volatility of fuel prices given its strategies for thermal generator management. In contrast to supply-side management, DSM is concerned with electrical load levels and usage patterns and is therefore unaffected by external factors. Therefore, DSM becomes more beneficial than supply-side management as electricity demands continue to grow at a rate that exceeds the expansion rate of power systems. Many studies have focused on the load control techniques of DSM [6], the roles of DSM in the electricity market [7], the economic benefits of DSM [8], the impacts of DSM on the industrial and residential sectors [9,10], the interactions of DSM with other smart grid technologies [11], the business models of DSM [12], the impacts of DSM on power system reliability [13], the optimization techniques of DSM [14,15] and the load forecasting and dynamic pricing schemes of DSM [16]. Moreover, DSM has been implemented with promising outcomes in various countries, such as the UK [17], China [18], North America [19], Kuwait [20] and Turkey [21].

Nevertheless, a joint investigation on the impacts of DSM on the economic performance, environmental friendliness, operation and reliability of power systems is unavailable. Such an investigation is timely given that current power systems are required to be holistic and should consider engineering and societal requirements. Although past surveys and studies on individual issues of power systems are commendable and important, a joint analysis will provide novel insight on the impacts of DSM on modern power systems. Such insight is particularly crucial given the recent advent of smart grid technologies. In view of the identified gaps, this review paper focuses on studies on the joint impacts of DSM on power systems.

The remainder of this paper is organized as follows: a summary of DSM techniques is given in Section 2. The impacts of DSM on power systems from the economic, market-wide performance, environmental, operational and reliability perspectives are presented in Section 3. A discussion of the reviews provided in Sections 2 and 3 is given in Section 4. Finally, novel research gaps and directions for future work are suggested in Section 5.

2. Overview of DSM Techniques

DSM is an initiative implemented by electricity utilities to encourage consumers to adopt procedures and practices that are advantageous to both parties [22]. These practices include any activity that aims to change load shapes by influencing the electricity consumption behavior of consumers [23]. Notably, the implementation of DSM increases the complexity of existing power systems because the adequate performance of DSM requires monitoring power system loads and generators [24]. Consequently, the deployment of sensors, the provision of incentives to participants of DSM programs and the performance of the general activities of DSM will incur additional expenditures. However, as we will later elucidate in Section 3, the benefits of DSM far outweigh its drawback of increased power system cost.

Figure 1 shows that DSM consists of energy efficiency, demand response and strategic load growth. Demand response is normally performed through peak clipping, valley filling or load-shifting activities or any combination of these techniques [22]. Demand response is also known as flexible load shape because of the flexibility exhibited by the activities.

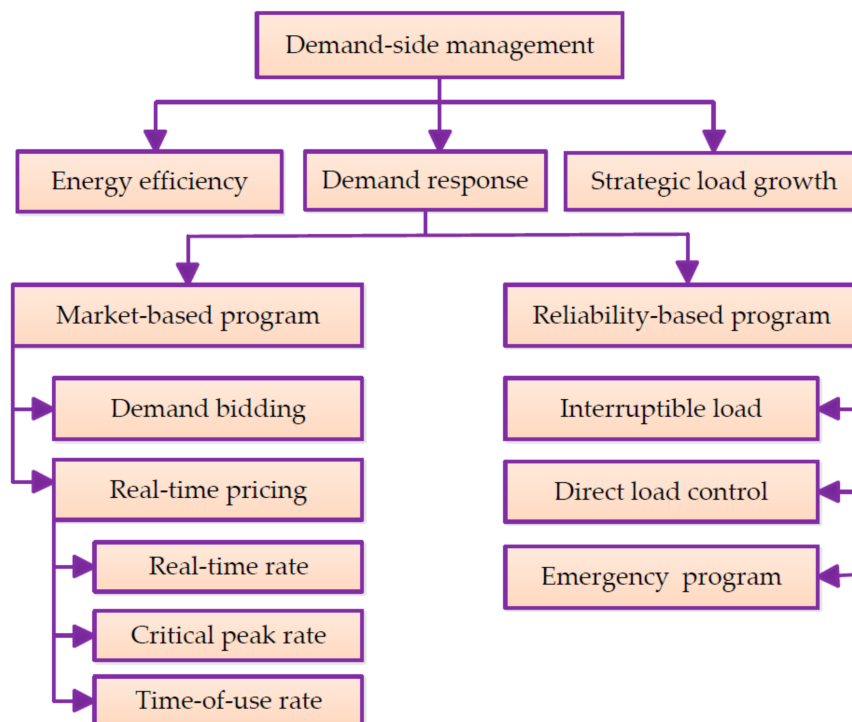


Figure 1. Various DSM (Demand-side management) techniques.

2.1. Energy Efficiency

Energy efficiency is defined as a long-term conservation strategy that aims to save energy and reduce demand through energy-efficient processes. Examples of energy-efficiency programs include house-appliance efficiency enhancement and weatherization [25]. Weatherization involves protecting a building from external elements, such as wind and sunlight and upgrading buildings to decrease energy consumption and losses. The implementation of energy-efficiency programs can decrease demands during on-peak times and average power system costs, as well as postpones the need to expand power system capacity [26]. Energy-efficient strategies include:

1. Adopting energy-efficient buildings and appliances to optimize energy consumption and encouraging the energy-conscious behavior of users [27].
2. Improving and conducting the regular maintenance of electrical equipment [25] by recovering heat waste, enhancing maintenance procedures, using modern equipment with optimized designs and practicing cogeneration [27].
3. Improving the efficiency of power transmission and distribution networks by using (1) distributed generation; (2) advanced control systems for voltage regulation, three-phase balancing, power factor correction and data acquisition and analysis in supervisory control and data acquisition systems; (3) modern technologies, such as low-loss transformers, gas installation substations, smart metering and fiber-optics for data acquisition and (4) high-transmission voltages [27].

2.2. Demand Response

Demand response (DR) involves a short-term load manipulation program that aims to influence energy consumption behavior. DR is defined as “the changes in electric usage by end-use consumers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale prices or when system reliability is jeopardized” [28]. Given that one of the advantages of DR is that it affects load directly, other DSM techniques are gradually being replaced by DR programs in the new electricity market environment [29].

DR is performed using either valley filling to build loads during off-peak periods [30]; peak clipping to reduce loads during on-peak periods [18] or load shifting, which combines valley-filling and peak-clipping activities [22].

As shown in Figure 1, DR programs are further divided into either reliability-based or market-based DR programs [31]. In reliability-based DR programs, consumers decrease their loads and/or voluntarily or involuntarily participate in controlled appliance use. In turn, consumers derive economic incentives by enrolling in this program. By providing real-time electricity market prices, market-based DR programs provide consumers with the options to adjust electricity consumption.

Reliability-based DR programs consist of the following:

1. Interruptible load program. This program is usually applied by large industrial and commercial consumers who can shut down their load for a short duration. In this program, consumers receive discounted electricity rates as compensation for accepting service interruptions. However, they can also be penalized if they do not participate in the program when required.
2. Direct load control program. In this program, the utility is allowed to directly interrupt or reduce consumer power supply during peak demand times after consumers are notified. In return, interrupted consumers receive compensation [28].
3. Emergency program. Consumers are given incentives to reduce their demand during system contingencies. In contrast to the interruptible load program, this program does not impose any penalties if consumers cannot participate [32].

Market-based DR programs consist of the following:

1. Demand bidding program: This program allows major consumers to bid for specific load curtailments. Consumers stay at a fixed rate and they receive high payments when wholesale electricity prices are high [28].
2. Real-time pricing program: Electricity production costs fluctuate over time and average system costs are fixed without considering its undesirability, particularly for large commercial and industrial consumers. To address these issues, the real-time pricing program is introduced and implemented through the following [31]:
 - a. Time-of-use rate. This rate is a predefined electricity price offered over a wide range of time periods, that is, seasonal, monthly, weekly or daily. The rate is voluntary and reflects basic production costs to decrease consumer demands during periods of high prices [28].
 - b. Critical peak rate. This rate offers consumers dynamic pricing that reflects actual market costs during critical peaks. This rate is usually offered a day ahead of the expected peak and is predefined but may be dynamic when necessary. Critical peak pricing rates can be used to improve power system reliability because they reflect the system state. Hence, if appropriate critical peak pricing signals are sent out, consumers may participate by decreasing load during system-stress events [31].
 - c. Real-time rate. In this program, consumers pay rates that are a function of actual market rates. Prices are usually supplied hourly or a day ahead to enable preplanning. Thus, rates will vary depending on the fluctuations in electricity supply [32].

2.3. Strategic Load Growth

Strategic load growth is defined as increased electrical energy load and is normally induced by utilities through dual fuel heating, heat pumps, thermal storage (thermal energy is stored during off-peak times for use during on-peak periods) and promotional rates. Strategic load growth is sometimes unavoidable because of the general increase in electricity demands, especially with the advent of electric vehicles of modern power systems [22] or air conditioning in warm countries [33].

3. Impacts of DSM on Power Systems

The impact of DSM on power systems is reviewed from the perspectives of the electricity market, environment and power system operation and reliability.

3.1. Electricity Market

Consumers mostly derive economic benefits in the form of incentive payments from participating in various DSM programs [28]. From the utility side, these economic benefits are usually in the form of reduced operating costs, decreased load losses and increased system efficiency [34]. The impacts of DSM on the electricity market model have also been widely investigated. Economic dispatch and DR have been integrated to enhance system efficiency [35]. Unit commitment and DSM have been combined to improve electricity market performance and decrease operational system cost [36,37]. Dynamic economic dispatch, which incorporates different penetration levels of wind energy, has been utilized to evaluate the impact of DSM on operation cost [38]. The time-of-use rate has been implemented on distribution networks with large industrial and commercial loads to simultaneously decrease utility and consumer costs [39]. The DR program can relieve market power in the case of limited power supply and transmission-line constraint violations [40]. Moreover, the DR program also reduces the market risk of consumers and suppliers and the uncertainty and fluctuation of prices [27].

3.2. Environment

The decrease in energy production reduces greenhouse gas emissions and thus attenuates environmental damage [41–46]. Such a decrease can be achieved by ensuring the optimal scheduling and operation of base generation units and reducing the frequency of shutdowns and startups of generators because generator startup and ramping require fuel burning without electricity generation. Hence, decreasing startup and ramping frequencies can reduce emissions [47,48]. The impact of DSM on environmental performance has been addressed in the literature. For example, the possible environmental benefits of load management by Swedish electrical utilities have been determined [48]. Power generation expansion planning that incorporates DSM with the objective functions of environmental impact associated with the installed power capacity and energy output has been presented [41]. A new mixed-integer programming-based structure for cost-and-emission-based maintenance scheduling associated with DR programs has been suggested [42,43]. The environmental impact of DSM and the potential environmental tradeoff between system cost and power plant emission reductions have been discussed [44]. The effect of a carbon tax and DSM programs in the Indonesian power sector has been discussed from the perspective of long-term integrated resource planning [45].

The above discussion shows that DSM programs can be integrated in the planning and operation of electrical power systems to mitigate environmental damage.

3.3. Power System Operation

The impact of DSM on power system operations are discussed from the following viewpoints:

3.3.1. Voltage Stability

Voltage stability refers to the ability of power systems to maintain acceptable voltages at all buses under normal operating conditions and after disturbances [49]. The proven ability of DSM to help achieve voltage stability in power systems is important for alleviating transmission congestions that are otherwise limited by bus-voltage violations [37]. On the other hand, DR can maintain frequency stability as well [50].

3.3.2. Transmission Congestion

As the DSM seeks to flatten the load profile and reduce the duration of peak load periods, the required transmission capacity decreases and this effect indirectly relieves transmission congestion [51,52]. Optimal power flow has been applied to maximize system benefits through the evaluation of the optimal allocation of demand-side resources [53]. Next, a procedure for determining the optimal busses for demand response has been developed on the basis of power transfer distribution factors, available transfer capability and dynamic DC optimal power flow [52].

3.3.3. Preventive Maintenance

Preventive maintenance is scheduled maintenance and is an outage that is managed and planned in advance; it is deferrable if necessary and includes component removal [1]. Preventive maintenance must be performed when system components approach the end of their useful lifespan or when failures are anticipated [54]. Preventive maintenance is periodically scheduled for generating units, transmission lines and distribution networks to reduce the risk of being out of service. Security-constrained preventive maintenance scheduling associated with demand response programs has been used to determine the optimal outage scheduling of generating units for minimizing emissions and decreasing maintenance, fuel and reserve costs [42,43].

3.3.4. Facility Upgrade

The peak demand period occurs approximately 5% of the load cycle and consumes nearly 1% of the total system energy. Therefore, building new generating units to satisfy this need is uneconomical. Although DSM and peaking generating units can efficiently resolve this issue [55], DSM programs can postpone investments in new generation units [41,56,57] and the expansion of transmission and distribution networks [58,59].

3.3.5. Renewable Energy Sources

Renewable energy sources are stochastic in nature, intermittent, unpredictable and uncontrollable. Many studies have assessed the intermittency of renewable energy sources either at the supply side as bulk units or at the demand-side as medium units. A priority-based demand response management and energy storage system for solar photovoltaic systems have been proposed to overcome the intermittency of power generation by solar photovoltaic [60]. DSM has been used to integrate the growing number of renewable energy sources in Portugal [61]. A probabilistic programming for smart microgrids has been implemented by considering demand response as compensation for the uncertainty caused by wind and solar power generation [62].

3.3.6. Power System Flexibility

DSM is an emerging flexible resource management strategy and exerts the dual impact of decreasing electricity demand and allowing efficient and flexible system management [63]. Power systems with highly mixed renewable energy sources are less likely to meet consumer demands than conventional systems with only fossil-fuel generators. Although this condition rarely occurs because of the ancillary services provided by energy storage systems, the financial implications of an electricity outage and possible blackout cascade are too massive to be ignored. In this context, DSM can be extremely valuable because it decreases electricity consumption during times of peak demand and low power generation by renewable energy sources. DSM is an alternative tool for increasing the flexibility of newly launched nuclear power plants [64]. A technique for optimizing the balance between DSM and the flexibility provided by fast-ramping generating units in a mixed-generation system has been investigated [65].

3.4. Power System Reliability

Power system reliability is a crucial concern during the design, planning and operating stages. System security and system adequacy are two fundamental features of power system reliability. System adequacy is concerned with the existence of sufficient equipment and facilities in the system to fulfil consumer demand. System security is related to the capability of the system to respond to disturbances [1]. The analysis of power system reliability is divided into three hierarchical levels (HLs) [1]. HL1 involves the analysis of the generation facility, HL2 considers the analysis of the generation and transmission facilities and HL3 considers the analysis of an additional distribution facility. Only HL1 and HL2 studies are regularly performed given that complete HL3 studies are highly complex because of their large problem scale. Thus, the distribution network is normally analyzed individually and separately from the generation and transmission systems.

3.4.1. Impact of DSM on the HL1 Assessment of Power System Reliability

In HL1 power system studies, only the capability of the power generations to meet load demands is investigated. In this case, the transmission and distribution networks are considered fully reliable. Various notable HL1 reliability analyses in the context of DSM are provided in Table 1. In this table, the contributions, benefits and limitations of the studies are compared.

Table 1. Comparison of notable works on the impacts of DSM on HL1.

Source	Contribution	Benefits	Limitation
[66]	Evaluated DSM impact on generating system reliability using the operating consideration (OPCON) model.	Modelled several unit and system operating considerations, such as unit duty cycle, operating reserve policy, outage postponability and unit commitment policy.	Insufficient DSM model that requires expansion to involve other scenarios, such as energy recovery and load diversity.
[67]	Assessed the impact of direct load control on the reliability of the generating system.	Preserved the temporal correlation between system load and available generating capacity.	Did not consider dynamic system performance, e.g., partial outage, load uncertainty and maintenance requirements.
[68]	Evaluated the impact of DSM on the reliability of the generating system and on the production costs of two interconnected systems.	Applied energy storage systems as a DSM activity and evaluated economic and reliability impacts.	Did not comprehensively investigate the diversity and types of energy storage systems; did not provide optimal load management performance in terms of reliability and production cost and did not use the energy-based reliability index.
[69]	Evaluated the impact of DSM on the reliability of the generating system and energy consumption.	Analytically modelled DSM and subjected the load-curve pattern to load-duration curve modelling.	Did not quantify the effects of DSM on the chronological hourly load curve.
[70]	Illustrated the integration of supply-side and demand-side planning in reliability cost and reliability worth analysis.	Quantified the effects of DSM on the chronological hourly load curve. Simulated 20 new load models. Investigated the impacts of implementing diverse DSM activities, except flexible load shape, on the worth, reliability and cost of the generating system.	Did not involve production cost and environmental impact and was mostly based on a total system load profile that did not directly include individual load -sector compositions.
[71]	Estimated the impacts of DSM impacts on the reliability of the generating system on the basis of future market penetration levels and power/energy reductions of DSM applications.	Modelled energy recovery by accounting for the considerations of DSM priority penetration and uncertainties.	Did not consider the diversity of DSM activities and individual load sector compositions.
[72]	Used an analytical method to study the impact of DSM on capacity requirements and energy consumption in probabilistic production costing methodology.	Investigated integrated resource planning requirements and modelled all DSM activities except for flexible load shape.	Did not consider environmental impact.

Table 1. Cont.

Source	Contribution	Benefits	Limitation
[73]	Probabilistically analyzed the impact of DSM on loss-of-load probability, energy not served, energy consumption and cycling costs of power plants.	Presented the importance of incorporating the cycling costs of power plants in the cost-effectiveness analysis of DSM programs. Studied the avoided start-up cost. Modelled all DSM activities except for flexible load shape.	Did not model peaking and intermittently operating units in the reliability framework.
[74]	Evaluated the impact of load shifting on the reliability of the generating system and the carrying capacity of the peak load in the presence of load forecast uncertainty.	Presented load forecast uncertainty.	Did not consider production cost impact, individual load sector compositions and customer damage function.
[75]	Evaluated the impact of load shifting on the reliability of the generating system and on load shapes.	Considered load diversity (seven different customer load sectors).	Did not consider the effects of load shifting on customer damage function, DSM activity diversity and production cost.
[76]	Evaluated the effect of implementing interruptible loads on reserve allocation in an electricity supply system. Evaluated whether the impact of the penalty scheme can maintain and/or improve the operation of the electricity supply system.	Involved electricity market environment, lost load value and unit commitment. Imposed a penalty cost on interruptible service providers whose loads are supposed to be interrupted.	Did not model real-time production cost and did not assess the customer damage function.
[77]	Proposed a framework for the long-term analysis of the electricity market to assess the impacts of demand response and smart-metering infrastructure implementation on market price fluctuations and system reliability.	Analyzed demand and supply uncertainties in a probabilistic manner. Explored interactions among generators under price-responsive demand. Strategic interactions between generators and price-responsive demand enabled by smart metering were considered in the framework. Presented a case study on state of Korean electricity markets in 2010.	Did not consider load forecast and smart-metering uncertainty.
[78]	Investigated the reliability- driven and market-driven measures of DR on the reliability of the generating system and system cost.	Determined the optimal scheme for implementing demand-side resources, the optimal commitment status of units and the optimal risk level of the system. Presented the value of lost load, the economic model of responsive loads and the model of risk-cost-based unit commitment problem mixed with demand-side resources.	Did not use the duration and frequency of interruption as reliability indices.
[79]	Evaluated the contributions of DR and energy storage systems to supply adequacy, as well as the impacts of the characteristics of energy payback, the flexibility of DR and the capacity and efficiency of the energy storage system.	Modelled the operational flexibility, energy payback and constraints of DR and energy storage systems.	Did not address the diversity of energy storage systems.
[80]	Integrated DSM and supply-side management in generation expansion planning.	Assessed the economic, flexibility level, adequacy of supply and environmental influence of RES, DSM and supply-side management on an existing peak-deficit power system in Tamil Nadu, India.	Did not consider the penetration of energy storage systems, the diversity of DSM activities and the uncertainty of flexible resources.

3.4.2. Impact of DSM on the HL2 Assessment of Power System Reliability

HL2 or composite electrical power systems consider the capability of transmission lines to transfer electrical energy from the generating side to the consumer side. This task involves system behaviors, such as power flow through lines and random line and generator failures. The impact of DSM activity or technique on HL2 has been widely investigated and has been compared in terms of their contribution, benefits and limitations as shown in Table 2.

Table 2. Comparison of notable works on the impacts of DSM on HL2.

Source	Contribution	Benefits	Limitation
[81]	Implemented DSM for the long-term assessment of the operating reserve. Evaluated possible scenarios for the implementation of interruptible load in DSM.	Illustrated the importance of DSM as a cost-saving opportunity in the new competitive electricity market by evaluating the system and societal cost savings achieved on the basis of interruptible load and customer interruption cost.	Excluded individual load sector compositions and frequency and duration-based reliability indices.
[82]	Evaluated the impacts of DSM on composite generation and transmission system reliability.	Presented all DSM activities except for flexible load shape. Modelled composite DSM actions in diverse areas of the power system.	Employed DC optimal power flow-based optimal load curtailment objective. Required the assessment of the customer damage function.
[83]	Implemented supply- and demand-side contingency management in the reliability assessment of hybrid power markets.	Managed supply- and demand-side contingency. Introduced a model to enable an independent system operator to coordinate reserve and load curtailment bids for contingency states and balance reliability worth and cost. Determined load curtailments and generation redispatch for a contingency state by minimizing the market interruption cost through an optimization technique.	Assumed all bidding costs as constant and thus generated impractical and inaccurate cost models. Excluded generation redispatch costs and transmission line contingencies from the objective function.
[84]	Proposed an optimization technique to determine load curtailment and generation redispatch for each contingency state in the reliability evaluation of restructured power systems with the Poolco market structure. Aimed to minimize the total system cost, which includes generation, reserve and interruption costs and is subject to market and network constraints.	Applied the reliability management of a power system during restructuring and deregulation. Presented a model for the contingency management of a Poolco power market. Included generation and reserve biddings, reliability considerations and transmission network constraints in reliability evaluation.	Implemented load shedding as a corrective action after contingencies. Did not consider mixing between load shedding as corrective and preventive actions. Did not model the penalty scheme.
[85]	Implemented DR as a generation alternative to improve the reliability indices of the system and load point.	Constructed a reliability model of demand resource based on customer behaviors. Associated DR availability and unavailability with the simple two-state model.	Did not consider partial DR unavailability, large test systems, individual load sector compositions and customer damage function assessment.
[86]	Presented reliability-based DR planning programs to demonstrate the superiority of nodal evaluation and prioritization of DR programs to improve reliability.	Evaluated the effects of employing DR programs for global and nodal prioritizing.	Required large test systems and individual load sector compositions.
[87]	Assessed the impact of interruptible load location on the economic performance and reliability of the system using security-constrained unit commitment in the presence of wind power.	Assessed the impact of the simultaneous participation of interruptible loads and wind power generation on system costs and reliability. Discussed the economic evaluation of wind power uncertainty, wind farm locations and spinning reserve of generation units.	Did not involve frequency and duration-based reliability indices.
[37]	Assessed the influence of emergency DR programs on reliability.	Investigated the efficiency of integrating DR into the problem of security-constrained unit commitment to improve both social welfare and reliability indices. Considered the value of lost load.	Did not evaluate the effect of payback energy on the value of lost load. Did not involve frequency and duration-based reliability indices and DR uncertainty.
[88]	Studied the impacts of DR programs on the short-term reliability assessment of wind-integrated power systems.	Presented a new algorithm for short-term reliability evaluation. The algorithm includes the effects of time and the initial states of components and involves a multi segment optimal power-flow approach to model the lead-time of DR and reserve resources and to account for the uncertainties associated with DR programs.	Ignored the uncertainty of wind power.

Table 2. Cont.

Source	Contribution	Benefits	Limitation
[89]	Studied the impacts of DR scheduling on reliability and economic indices, particularly when emergency energy prices drive load recovery.	Identified the synergy between dynamic thermal ratings and DR in presence of wind-generating units to assess economic and reliability impacts. Proposed a probabilistic framework for optimal DR scheduling in the day-ahead planning of transmission networks.	Ignored the uncertainty of DR.
[90]	Proposed a novel economic dispatch model integrated with wind power. This model considers incentive-based DR and reliability measures and combines the probability distribution of the forecast errors of load and wind power, as well as the outage replacement rates of units.	Proposed a model that considers the forecasting errors of wind power and load, the outage replacement rate of all units and customer power consumption response to the incentive price. Optimized the load profile with DR to depress the dispatch influence caused by antipeak-shaving and the intermittence of wind generation. Added the cost of expected energy not supplied to the objective to achieve an optimal equilibrium point between economy and the reliability of power system operation.	Ignored the diversity of DR program.
[91]	Described a practical methodology to identify interruptible loads by node to compensate for energy interruptions for nodal consumers willing to reduce their energy consumption.	Based the pricing implementation of a nodal reliability service on the contingency assessment of $N - 2$ orders for transmission lines.	Did not consider the uncertainty of wind power and the value of lost load. Used DC- optimal power flow mathematical formulation.
[40]	Implemented renewables (wind generations and photovoltaic) and DSM resources in a capacity market environment to reduce reliability cost and losses, mitigate market power and enhance voltage profile and system loadability.	Modelled the optimal location, capacity and price of DSM resources and the optimal location of wind farms and photovoltaic set-ups. Determined reliability cost minimization from the perspective of system operator. Considered power loss, voltage profile and system load ability.	Did not calculate reliability indices.
[92]	Quantified the reliability impact of the interactions between DSM and the dynamic thermal ratings system on a composite power system. Evaluated the impact of load shifting on load demand curves from the system, bus and load sector levels. Developed a load model starting from the perspective of the load sectors at each bus to achieve modification and a new collective hourly load curve for the system was obtained by combining loads at all buses.	Explored various DSM measures and dynamic thermal rating systems in the transmission network. Considered the correlation effects of line ratings and weather when modelling the dynamic thermal ratings system.	Used DC- optimal power flow mathematical formulation. Did not consider the diversity of DSM activities.

3.4.3. Impact of DSM on the Power System Distribution Network

Studies on HL3 and distribution network reliability use the load-point indices of HL2 as the input values of the distribution network. The distribution network possesses two configurations, namely, meshed and radial. Meshed distribution networks are assessed through the same approach as HL2. The evaluation of a radial distribution network is based on the analysis of failure mode and considers failures and restoration practices [93]. The implementation of DSM in HL1 and HL2 mainly aims to enhance load-point reliability indices. By contrast, the implementation of DSM in the reliability assessment of the distribution network mainly aims to reduce interruptions in service at the consumer side. Several notable studies on the reliability of DSM in the distribution network are compared in terms of their contribution, benefits and limitations as shown in Table 3.

Table 3. Comparison of notable works on the impacts of DSM on distribution networks.

Source	Contribution	Benefits	Limitation
[94]	Assessed the potential impacts of DR on major attributes of service reliability in a Finnish distribution network.	Comprehensively studied the potential impacts of DR on the major attributes of service reliability in a residential distribution network. Incorporated the obtained DR model into the reliability assessment of a Finnish distribution network. Proposed different levels for active customer penetration and customer discomfort.	Assumed that the balanced network is an ideal condition. Did not consider distributed generator (DG) penetration, DR uncertainty and islanding operation.
[95]	Assessed the potential impacts of DR on the major attributes of the operation of a Finnish distribution network. Studied the impacts of DR on different aspects of network operation, such as network losses, voltage profiles and service reliability.	Studied the impacts of DR potentials on load and voltage profiles, network losses and service reliability, as well as the potential impacts of individual responsive appliances.	Assumed that the balanced network is an ideal condition. Did not consider DG penetration, reactive power, DR availability, interruption cost and islanding operation.
[96]	Proposed a biobjective optimization model for the optimal siting and sizing of energy storage systems in a microgrid under a demand response program. The proposed objective optimization model included two different objective functions: (1) the minimization of total investment cost, total cost of microgrid and operation cost and (2) the minimization of loss of load expectation.	Modelled the optimal siting and sizing problem of energy storage systems in the microgrid by a mixed-integer non-linear program. Applied general algebraic modeling system software to solve the problem. Utilized the ϵ -constraint method to solve the proposed bi-objective optimization model. Determined the best solution among the obtained solutions through fuzzy satisfying technique.	Assumed that DG units operate at the unity power factor.
[97]	Proposed a methodology for the cost-effective improvement of system reliability through the allocation of distributed storage units in distribution systems. Primarily aimed to determine the optimal combination of storage units to be installed and the loads to be shed.	Optimized the costs of energy storage installation with respect to the reliability value, which is expressed as the customers' willingness to pay to avoid power interruptions. Adopted a probabilistic approach that accounts for the stochastic nature of system components. Proposed a two-stage model for the allocation of distributed storage units in distribution systems as a cost-effective means of improving system reliability. Adopted a value-based reliability approach that considers the customers' willingness to pay as the reliability value benefit of improved system reliability. Minimized the total annual costs comprising distributed storage installation, maintenance and interruption costs to determine the optimal combination of distributed storage units to be installed and the loads to be shed during all possible contingencies. Used a probabilistic approach to calculate power requirements from allocated DS units. The approach considered the stochastic nature of all of the system components, including loads and existing DG.	Did not consider energy payback, energy storage systems availability and DR uncertainty. Assumed that all droop controller parameters are identical and that the terminal voltage of each distributed storage unit is set at 1 per unit. Assumed that the DG synchronous generator has a unity power factor in grid-connected mode
[98]	Assessed the contribution of incentive-based DR to the supply adequacy of smart distribution systems. Illustrated the proposed approach by using a small-scale test case and a real regional distribution grid in China.	Proposed a new DR model and considered the variation in demand-side participation. Considered the effects of communication systems on DR realization. Used a hybrid algorithm combining operation optimization and reliability analysis. Considered variations in the availability of customer DR capabilities and willingness of users to participate.	Assumed that transmission lines are 100% reliable and that no possible contingencies exist in the network. Did not consider DG availability.

Table 3. Cont.

Source	Contribution	Benefits	Limitation
[99]	Assessed the reliability of industrial microgrids in the presence of DG and DR resources.	Applied widely used renewable energy generation technologies, such as wind and photo voltaic. Considered a number of scenarios to determine the DG output amount per hour. Applied the proposed method to IEEE-RBTS BUS2 standard network and to Mahmoud-Abad Industrial Zone Network in Isfahan, Iran.	Did not consider transmission line failure and DR availability.

4. Discussion

The potential benefits of DSM were reviewed in accordance with the area of effects (e.g., economic, environmental, market-wide based and technical impacts). Accordingly, a literature survey on the effects of DSM on the reliability of electrical power systems was conducted. The economic, environmental, market performance and overall technical benefits provided by DSM include (1) maintaining voltage stability; (2) relieving transmission congestion; (3) increasing the flexibility of preventive maintenance scheduling; (4) postponing the required upgrading of electrical power system facilities; (5) balancing energy resource; (6) mitigating the drawbacks posed by the intermittency of renewable energy sources; (7) increasing the flexibility of electrical power system operation; (8) reinforcing integrated resource planning; (9) increasing the utilization of renewable energy sources; (10) reducing the startup and shutdown of thermal units that require excessive starting costs; (11) maintaining the reliability of electrical power systems and reducing the risk of being out of service; (12) avoiding capital costs; (13) increasing efficiency; (14) reducing running costs; (15) enhancing power quality, security and power factor (16) increasing consumer satisfaction (17) improving the market performance of electricity power systems; and finally (18) mitigating environmental damage. These improvements can yield significant secondary benefits, such as reductions in losses and premature ageing and leads to the adoption of efficient residential appliances and industrial equipment. These benefits are summarized in Figure 2.

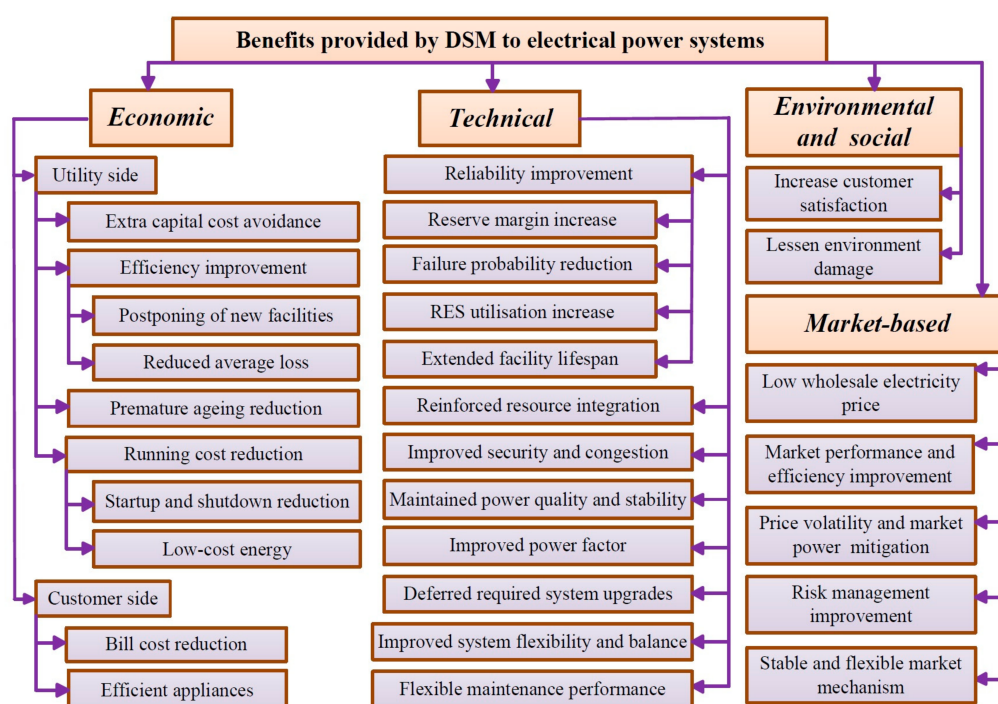


Figure 2. Benefits achieved by the DSM program.

Assessing the effects of DSM on electrical power systems is useful to the field of integrated resource planning because this field requires the extensive investigation of the potential mutual benefits achieved by DSM. Therefore, we considered the general impacts of DSM on reliability to enable readers to keep abreast of recent research on electrical power systems.

Reliability-based DSM programs can be implemented (1) when the load increases rapidly and exceeds adequacy limits and (2) after contingencies (e.g., occurrences of faults and violations of operational limits). In these two cases, the load management program accordingly decides to shift or curtail the load. Thus, load management programs maintain system adequacy and security.

Load shifting is the main contributor to load management. It influences the load curve and significantly improves cost and reliability. Furthermore, energy recovery after peak shaving is limited by numerous factors, such as the amount of curtailed energy; the availability of committed generation units and other facilities at the time of recovery; the percentage limits of energy supposed to be recovered; the comfort of the consumer and the availability of DSM program itself. In accordance with these factors, load-shifting programs can be classified as preventive and corrective load shifting. Corrective load-shifting program is implemented after fault occurrence and preventive load-shifting program is implemented when the system is under increased risk or when electrical power systems are jeopardized. Both of these program types can be implemented to ensure the optimal level of reliability and production costs.

The customer damage function or lost-load value is also affected by the DSM program. Peak clipping decreases risk but drastically increases consumer dissatisfaction if implemented without energy recovery. Valley filling slightly affects electrical power system reliability and consumer satisfaction. DSM is a complementary component of and a highly flexible tool for the management of modern electrical power grids. DSM programs can reduce the boundaries of risk levels, particularly in maintaining a reserve margin, if integrated with the startup and shutdown actions of peaking and intermittently operating units. Load shaping links two or more operational performances to overcome their drawbacks, such as the intermittency of renewable energy sources and the limited capacity of energy storage systems.

Many facilities and equipment must be installed (e.g., sensors, communication media and measurement and monitoring devices) to implement DSM. Although these installations may involve high initial costs, they provide mutual benefits to the network and the consumers. These benefits involve enhancing the controllability and observability of the network. In addition, integrating DSM with modern and steadily developing trends and technologies (e.g., smart grid, microgrid, dynamic thermal ratings, energy storage systems, plug-in electrical vehicle, flexible AC transmission systems and high-voltage DC transmission line systems) will increase system efficiency. The continuous monitoring of the load profile will also help specify electricity prices in real time. Accordingly, the thermal ratings of overhead lines can be monitored in real time.

The significant topics that remain to be investigated are as follows:

1. DSM affects the economic, environmental and market-wide performances of electrical power systems. Nevertheless, few works have assessed the mutual benefits provided by DSM by comparing the impacts of DSM on the economic, environmental and market-wide performances of electrical power systems with those on the reliability of electrical power systems. Thus, many potential advantages of DSM have not been yet thoroughly and quantitatively explored.
2. Electrical power system utilities and the electricity market have recently focused on resource integration to increase efficiency. The potentially significant role of DSM in energy resource integration must be considered.
3. Energy efficiency is a promising trend because of its contribution to reducing long-term energy costs and its potential impacts on reliability enhancement. However, this issue has yet to be quantitatively explored.

4. High-voltage DC transmission line systems are different from high-voltage AC transmission lines in many aspects, such as power flow, failure rate and contingencies. The impacts of DSM on the reliability of electrical power systems have not been examined from this perspective.
5. The cost of implementing DSM activities has not been assessed in detail from the perspective of evaluating reliability worth/cost accurately in the presence of DSM. Given that DSM exhibits its own advantages and drawbacks, the possible defects of DSM must be carefully studied.
6. The assumptions on the behavior of power systems (e.g., ageing effect, partial outage of generation units, duty cycle and failure initiation of peaking and intermittent operating units, uncertainties, multiarea systems, natural disasters, dynamic thermal ratings and scheduled maintenance) were not considered in most of the studies cited above. Forecast uncertainties (e.g., load magnitude and duration, fuel price, failure rate, DSM measures and renewable energy sources intermittency) in the presence of DSM are poorly investigated. Future works should thoroughly and quantitatively investigate these issues in the implementation of preventive and corrective load shifting.
7. DSM programs increase the choices available to planners and decision makers by providing an alternative tool for power generation, transmission and distribution. An accurate assessment needs to be conducted when deciding to implement a DSM program or to build new generating units or transmission lines during expansion planning.
8. DSM programs mitigate environmental damage by increasing the utilization of renewable energy sources, reducing the startup and shutdown of peaking and intermittent operating units and deferring the development of additional infrastructure to meet peak demand. Nevertheless, few studies have evaluated the environmental impacts of DSM.
9. Other issues in the presence of load shaping should also be explored. These issues include finding the optimal level of reliability that corresponds to the optimal level of production cost and consumer satisfaction; exploring the application of the optimal ancillary service of DR as a spinning reserve over the MW spinning reserve; addressing the diversity of renewable energy sources, energy storage system types and applications and finding a fair rate for the DR program framework in the environment of the electricity market.

5. Conclusions

Load-shaping strategies enable power system operators to maintain system reliability and costs within the required standards and limits. DSM programs offer promising solutions and considerably improve the reliability and financial performance of electrical power systems. This paper provides a review of the potential impacts of DSM on the overall performance of electrical power networks. The review is based on the economic, environmental, market-wide based and technical impacts of DSM. Accordingly, an extensive literature survey on the effects of DSM on electrical power reliability is presented on the basis of the heretofore level of power system grid facilities. This paper also presents the potential benefits achieved by the implementation of DSM in electrical power networks. The research gaps within the field of DSM are also identified. Finally, the conclusion that DSM implementation improves economic, environmental and market performance and reliability is presented. Thus, DSM is a highly flexible tool and a complementary component of the management of electrical power grids in the future.

Acknowledgments: This work is partly supported by the USM short term grant 304/PELECT/60313051 and the USM Bridging grant: 304.PELECT.6316117.

Author Contributions: Hussein Jumma Jabir and Jiashen Teh conceived and designed the experiments; Dahaman Ishak analyzed the data; Hamza Abunima contributed materials/analysis tools; Hussein Jumma Jabir wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Billinton, R.; Allan, R.N. *Reliability Evaluation of Power Systems 2013*; Plenum: New York, NY, USA, 1984.
2. Freeman, R. Managing energy: Reducing peak load and managing risk with demand response and demand side management. *Refocus* **2005**, *6*, 53–55. [[CrossRef](#)]
3. Martínez-Lao, J.; Montoya, F.G.; Montoya, M.G.; Manzano-Agugliaro, F. Electric vehicles in Spain: An overview of charging systems. *Renew. Sustain. Energy Rev.* **2017**, *77*, 970–983. [[CrossRef](#)]
4. Saini, S. Conservation v. generation: The significance of Demand-Side Management (DSM), its tools and techniques. *Refocus* **2004**, *5*, 52–54. [[CrossRef](#)]
5. United Nations Industrial Development Organization. Supply Side Management—Module 13. Sustainable Energy Regulation and Policy Making for Africa. Available online: <http://africa-toolkit.reEEP.org/modules/Module13.pdf> (accessed on 5 February 2018).
6. Morgan, M.G.; Talukdar, S.N. Electric power load management: Some technical, economic, regulatory and social issues. *Proc. IEEE* **1979**, *67*, 241–312. [[CrossRef](#)]
7. Sharifi, R.; Fathi, S.; Vahidinasab, V. A review on demand-side tools in electricity market. *Renew. Sustain. Energy Rev.* **2017**, *72*, 565–572. [[CrossRef](#)]
8. Conchado, A.; Linares, P. The economic impact of demand-response programs on power systems. A survey of the state of the art. *Handb. Netw. Power Syst. I* **2012**, WP 02/2010, 281–301.
9. Shoreh, M.H.; Siano, P.; Shafie-khah, M.; Loia, V.; Catalão, J.P. A survey of industrial applications of demand response. *Electr. Power Syst. Res.* **2016**, *141*, 31–49. [[CrossRef](#)]
10. Esther, B.P.; Kumar, K.S. A survey on residential demand side management architecture, approaches, optimization models and methods. *Renew. Sustain. Energy Rev.* **2016**, *59*, 342–351. [[CrossRef](#)]
11. Khan, Z.A.; Ahmed, S.; Nawaz, R.; Mahmood, A.; Razzaq, S. Optimization based individual and cooperative DSM in Smart Grids: A review. *Power Gener. Syst. Renew. Energy Technol.* **2015**, *2015*, 1–6.
12. Behrangrad, M. A review of demand side management business models in the electricity market. *Renew. Sustain. Energy Rev.* **2015**, *47*, 270–283. [[CrossRef](#)]
13. Kirby, B.J. Demand response for power system reliability: FAQ. *Oak Ridge Nat. Lab.* **2006**. [[CrossRef](#)]
14. Hussain, I.; Mohsin, S.; Basit, A.; Khan, Z.A.; Qasim, U.; Javaid, N. A Review on Demand Response: Pricing, Optimization, and Appliance Scheduling. *Procedia Comput. Sci.* **2015**, *52*, 843–850. [[CrossRef](#)]
15. Vardakas, J.S.; Zorba, N.; Verikoukis, C.V. A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 152–178. [[CrossRef](#)]
16. Khan, A.R.; Mahmood, A.; Safdar, A.; Khan, Z.A.; Khan, N.A. Load forecasting, dynamic pricing and DSM in smart grid: A review. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1311–1322. [[CrossRef](#)]
17. Warren, P. A review of demand-side management policy in the UK. *Renew. Sustain. Energy Rev.* **2014**, *29*, 941–951. [[CrossRef](#)]
18. Ming, Z.; Song, X.; Mingjuan, M.; Lingyun, L.; Min, C.; Yuejin, W. Historical review of demand side management in China: Management content, operation mode, results assessment and relative incentives. *Renew. Sustain. Energy Rev.* **2013**, *25*, 470–482. [[CrossRef](#)]
19. Wang, Q.; Zhang, C.; Ding, Y.; Xydis, G.; Wang, J.; Østergaard, J. Review of real-time electricity markets for integrating distributed energy resources and demand response. *Appl. Energy* **2015**, *138*, 695–706. [[CrossRef](#)]
20. Alasser, R.; Tripathi, A.; Rao, T.J.; Sreekanth, K.J. A review on implementation strategies for demand side management (DSM) in Kuwait through incentive-based demand response programs. *Renew. Sustain. Energy Rev.* **2017**, *77*, 617–635. [[CrossRef](#)]
21. Zehir, M.A.; Batman, A.; Bagriyanik, M. Review and comparison of demand response options for more effective use of renewable energy at consumer level. *Renew. Sustain. Energy Rev.* **2016**, *56*, 631–642. [[CrossRef](#)]
22. Gellings, C.W. Evolving practice of demand-side management. *J. Mod. Power Syst. Clean Energy* **2017**, *5*, 1–9. [[CrossRef](#)]
23. Limaye, D. Implementation of demand-side management programs. *Proc. IEEE* **1985**, *73*, 1503–1512. [[CrossRef](#)]
24. Sim, S. *Electric Utility Resource Planning: Economics, Reliability, and Decision-Making*; CRC Press: Boca Raton, FL, USA, 2011; p. 332.
25. United Nations Industrial Development Organization. Energy Efficiency Technologies and Benefits-Module 12. Sustainable Energy Regulation and Policy Making for Africa. Available online: https://www.unido.org/fileadmin/media/documents/pdf/EEU_Training_Package/Module12.pdf (accessed on 9 February 2018).

26. Bellarmine, G.T. Load management techniques. In Proceedings of the IEEE Southeastcon 2000, Nashville, TN, USA, 9 April 2000; pp. 139–145.
27. Abaravicius, J. *Demand Side Activities for Electric Load Reduction*; Department of Energy Sciences, Lund University: Skanney, Sweden, 2007; p. 153.
28. Qdr, Q. *Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them*; U.S. Department of Energy: Washington, DC, USA, 2006.
29. Walawalkar, R.; Fernands, S.; Thakur, N.; Chevva, K.R. Evolution and current status of demand response (DR) in electricity markets: Insights from PJM and NYISO. *Energy* **2010**, *35*, 1553–1560. [CrossRef]
30. Gellings, C.W. Standars Corner IEEE PES Demand-Side Management Subcommittee. *IEEE Power Eng. Rev.* **1986**, *PER-6*, 9–12.
31. York, D.; Kushler, M. *Exploring the Relationship between Demand Response and Energy Efficiency: A Review of Experience and Discussion of Key Issues*; American Council for an Energy-Efficient Economy: Washington, DC, USA, 2005.
32. Demand Response Discussion for the 2007 Long-Term Reliability Assessment, North 109 American Electric Reliability Corporation of Site. Available online: <http://www.naesb.org/pdf2/dsmee052407w4.pdf>. (accessed on 19 February 2018).
33. Juaidi, A.; Montoya, F.G.; Gázquez, J.A.; Manzano-Agugliaro, F. An overview of energy balance compared to sustainable energy in United Arab Emirates. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1195–1209. [CrossRef]
34. Delgado, R.M. Demand-side management alternatives. *Proc. IEEE* **1985**, *73*, 1471–1488. [CrossRef]
35. Nguyen, D.H.; Narikiyo, T.; Kawanishi, M. Demand response collaborative management by a distributed alternating direction method of multipliers. *Innov. Smart Grid Technol.* **2016**, 759–764. [CrossRef]
36. Magnago, F.H.; Alemany, J.; Lin, J. Impact of demand response resources on unit commitment and dispatch in a day-ahead electricity market. *Int. J. Electr. Power Energy Syst.* **2015**, *68*, 142–149. [CrossRef]
37. Aghaei, J.; Alizadeh, M.I.; Siano, P.; Heidari, A. Contribution of emergency demand response programs in power system reliability. *Energy* **2016**, *103*, 688–696. [CrossRef]
38. Alham, M.H.; Elshahed, M.; Ibrahim, D.K.; El Zahab, E.E.D.A. Optimal operation of power system incorporating wind energy with demand side management. *Ain Shams Eng. J.* **2017**, *8*, 1–7. [CrossRef]
39. Kinhekar, N.; Padhy, N.P.; Gupta, H.O. Multiobjective demand side management solutions for utilities with peak demand deficit. *Int. J. Electr. Power Energy Syst.* **2014**, *55*, 612–619. [CrossRef]
40. Jalili, H.; Sheikh-El-Eslami, M.K.; Parsa Moghaddam, M. Reducing reliability cost in presence of renewables by demand side management resources. *Int. Trans. Electr. Energy Syst.* **2017**, *27*. [CrossRef]
41. Martins, A.G.; Coelho, D.; Antunes, H.; Clímaco, J. A multiple objective linear programming approach to power generation planning with demand-side management (DSM). *Int. Trans. Oper. Res.* **1996**, *3*, 305–317. [CrossRef]
42. Mollahassani-pour, M.; Abdollahi, A.; Rashidinejad, M. Investigation of market-based demand response impacts on security-constrained preventive maintenance scheduling. *IEEE Syst. J.* **2015**, *9*, 1496–1506. [CrossRef]
43. Mollahassani-Pour, M.; Rashidinejad, M.; Abdollahi, A.; Forghani, M.A. Demand Response Resources' Allocation in Security-Constrained Preventive Maintenance Scheduling via MODM Method. *IEEE Syst. J.* **2017**, *11*, 1196–1207. [CrossRef]
44. Reddy, B.S.; Parikh, J.K. Economic and environmental impacts of demand side management programmes. *Energy Policy* **1997**, *25*, 349–356. [CrossRef]
45. United Nations Industrial Development Organization. Demand Side Management-Module 14. Sustainable Energy Regulation and Policy Making for Africa. Available online: <http://africa-toolkit.reeeep.org/modules/Module14.pdf> (accessed on 8 February 2018).
46. Shrestha, R.M.; Marpaung, C.O. Supply-and demand-side effects of carbon tax in the Indonesian power sector: An integrated resource planning analysis. *Energy Policy* **1999**, *27*, 185–194. [CrossRef]
47. Holland, S.P.; Mansur, E.T. Is real-time pricing green? The environmental impacts of electricity demand variance. *Rev. Econ. Stat.* **2008**, *90*, 550–561. [CrossRef]
48. Abaravicius, J.; Pyrko, J. Load management from an environmental perspective. *Energy Environ.* **2006**, *17*, 583–601. [CrossRef]
49. Kundur, P.; Paserba, J.; Ajarapu, V.; Andersson, G.; Bose, A.; Canizares, C.; Hatziaargyriou, N.; Hill, D.; Stankovic, A.; Taylor, C.; et al. Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. *IEEE Trans. Power Syst.* **2004**, *19*, 1387–1401.

50. Babahajiani, P.; Shafiee, Q.; Bevrani, H. Intelligent demand response contribution in frequency control of multi-area power systems. *IEEE Trans. Smart Grid* **2016**, *9*, 1282–1291. [[CrossRef](#)]
51. Kumar, A.; Sekhar, C. DSM based congestion management in pool electricity markets with FACTS devices. *Energy Procedia* **2012**, *14*, 94–100. [[CrossRef](#)]
52. Dehnavi, E.; Abdi, H. Determining optimal buses for implementing demand response as an effective congestion management method. *IEEE Trans. Power Syst.* **2017**, *32*, 1537–1544. [[CrossRef](#)]
53. Hayes, B.; Hernando-Gil, I.; Collin, A.; Harrison, G.; Djokić, S. Optimal power flow for maximizing network benefits from demand-side management. *IEEE Trans. Power Syst.* **2014**, *29*, 1739–1747. [[CrossRef](#)]
54. Allan, R.N. *Reliability Evaluation of Engineering Systems: Concepts and Techniques*; Springer: Boston, MA, USA, 1983.
55. Billinton, R.; Huang, D. Peaking Unit Considerations in Generating Capacity Adequacy Assessment. *Elect. Comput. Eng.* **2006**, 386–389. [[CrossRef](#)]
56. Pina, A. Supply and Demand Dynamics in Energy Systems Modeling. Ph.D. Thesis, Technical University of Lisbon, Lisbon, Portugal, 2012.
57. Pina, A.; Silva, C.; Ferrão, P. The impact of demand side management strategies in the penetration of renewable electricity. *Energy* **2012**, *41*, 128–137. [[CrossRef](#)]
58. Hoff, T.E. Identifying distributed generation and demand side management investment opportunities. *Energy J.* **1996**, *17*, 89–105. [[CrossRef](#)]
59. Hajebrahimi, A.; Abdollahi, A.; Rashidinejad, M. Probabilistic multiobjective transmission expansion planning incorporating demand response resources and large-scale distant wind farms. *IEEE Syst. J.* **2015**, *11*, 1170–1181. [[CrossRef](#)]
60. Kandasamy, N.K.; Tseng, K.J.; Boon-Hee, S. A Virtual Storage Capacity Using Demand Response Management to Overcome Intermittency of Solar PV Generation. *IET Renew. Power Gener.* **2017**, *11*, 1741–1748. [[CrossRef](#)]
61. Moura, P.S.; De Almeida, A.T. The role of demand-side management in the grid integration of wind power. *Appl. Energy* **2010**, *87*, 2581–2588. [[CrossRef](#)]
62. Aghajani, G.R.; Shayanfar, H.A.; Shayeghi, H. Demand side management in a smart micro-grid in the presence of renewable generation and demand response. *Energy* **2017**, *126*, 622–637. [[CrossRef](#)]
63. Heydarian-Forushani, E.; Golshan, M.E.H.; Siano, P. Evaluating the benefits of coordinated emerging flexible resources in electricity markets. *Appl. Energy* **2017**, *199*, 142–154. [[CrossRef](#)]
64. Gitelman, L.; Gitelman, L.; Kozhevnikov, M. Fulfilling The Potential of Nuclear Power Industry through Demand Side Management. *Int. J. Sustain. Dev. Plan.* **2017**, *12*, 1043–1049. [[CrossRef](#)]
65. Rosso, A.; Ma, J.; Kirschen, D.S.; Ochoa, L.F. Assessing the contribution of demand side management to power system flexibility. In Proceedings of the 2011 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, 12–15 December 2011; pp. 4361–4365.
66. Patton, A.D.; Singh, C. Evaluation of load management effects using the OPCON generation reliability model. *IEEE Trans. Power App. Syst.* **1984**, PAS-103, 3229–3238.
67. Salehfar, H.; Patton, A.D. Modeling and evaluation of the system reliability effects of direct load control. *IEEE Trans. Power Syst.* **1989**, *4*, 1024–1030. [[CrossRef](#)]
68. Ahsan, Q. Load management: Impacts on the reliability and production costs of interconnected systems. *Int. J. Electr. Power Energy Syst.* **1990**, *12*, 257–262. [[CrossRef](#)]
69. Rahman, S. An efficient load model for analyzing demand side management impacts. *IEEE Trans. Power Syst.* **1993**, *8*, 1219–1226. [[CrossRef](#)]
70. Billinton, R.; Lakhanpal, D. Impacts of demand-side management on reliability cost/reliability worth analysis. *IEE Proc. Gener. Transm. Distrib.* **1996**, *143*, 225–231. [[CrossRef](#)]
71. Osareh, A.R.; Pan, J.; Rahman, S. An efficient approach to identify and integrate demand-side management on electric utility generation planning. *Electr. Power Syst. Res.* **1996**, *36*, 3–11. [[CrossRef](#)]
72. Malik, A.S. Simulation of DSM resources as generating units in probabilistic production costing framework. *IEEE Trans. Power Syst.* **1998**, *13*, 1528–1533. [[CrossRef](#)]
73. Malik, A. Modelling and economic analysis of DSM programs in generation planning. *Int. J. Electr. Power Energy Syst.* **2001**, *23*, 413–419. [[CrossRef](#)]
74. Huang, D.; Billinton, R. Impacts of demand side management on bulk system reliability evaluation considering load forecast uncertainty. In Proceedings of the 2011 IEEE Electrical Power and Energy Conference, Winnipeg, MB, Canada, 3–5 October 2011; pp. 272–277.

75. Huang, D.; Billinton, R. Effects of Load Sector Demand Side Management Applications in Generating Capacity Adequacy Assessment. *IEEE Trans. Power Syst.* **2012**, *27*, 335–343. [\[CrossRef\]](#)
76. Toh, G.; Gooi, H.B. Procurement of interruptible load services in electricity supply systems. *Appl. Energy* **2012**, *98*, 533–539. [\[CrossRef\]](#)
77. Joung, M.; Kim, J. Assessing demand response and smart metering impacts on long-term electricity market prices and system reliability. *Appl. Energy* **2013**, *101*, 441–448. [\[CrossRef\]](#)
78. Rahmani-andebili, M. Risk-cost-based generation scheduling smartly mixed with reliability-driven and market-driven demand response measures. *Int. Trans. Electr. Energy Syst.* **2015**, *25*, 994–1007. [\[CrossRef\]](#)
79. Zhou, Y.; Mancarella, P.; Mutale, J. Modelling and assessment of the contribution of demand response and electrical energy storage to adequacy of supply. *Sustain. Energy Grids Net.* **2015**, *3*, 12–23. [\[CrossRef\]](#)
80. Karunanithi, K.; Saravanan, S.; Prabakar, B.R.; Kannan, S.; Thangaraj, C. Integration of Demand and Supply Side Management strategies in Generation Expansion Planning. *Renew. Sustain. Energy Rev.* **2017**, *73*, 966–982. [\[CrossRef\]](#)
81. Fotuhi-Firuzabad, M.; Billinton, R. Impact of load management on composite system reliability evaluation short-term operating benefits. *IEEE Trans. Power Syst.* **2000**, *15*, 858–864. [\[CrossRef\]](#)
82. Zhou, M.; Li, G.; Zhang, P. Impact of Demand Side Management on Composite Generation and Transmission System Reliability. In Proceedings of the 2006 IEEE PES Power Systems Conference and Exposition, Atlanta, GA, USA, 29 October–1 November 2006; pp. 819–824.
83. Goel, L.; Aparna, V.P.; Wang, P. A framework to implement supply and demand side contingency management in reliability assessment of restructured power systems. *IEEE Trans. Power Syst.* **2007**, *22*, 205–212. [\[CrossRef\]](#)
84. Wang, P.; Ding, Y.; Goel, L. Reliability assessment of restructured power systems using optimal load shedding technique. *IET Gener. Transm. Distrib.* **2009**, *3*, 628–640. [\[CrossRef\]](#)
85. Kwag, H.G.; Kim, J.O. Reliability modeling of demand response considering uncertainty of customer behavior. *Appl. Energy* **2014**, *122*, 24–33. [\[CrossRef\]](#)
86. Moshari, A.; Ebrahimi, A. Reliability-based nodal evaluation and prioritization of demand response programs. *Int. Trans. Electr. Energy Syst.* **2015**, *25*, 3384–3407. [\[CrossRef\]](#)
87. Ramandi, M.Y.; Afshar, K.; Gazafroudi, A.S.; Bigdeli, N. Reliability and economic evaluation of demand side management programming in wind integrated power systems. *Int. J. Electr. Power Energy Syst.* **2016**, *78*, 258–268. [\[CrossRef\]](#)
88. Moshari, A.; Ebrahimi, A.; Fotuhi-Firuzabad, M. Short-term impacts of DR programs on reliability of wind integrated power systems considering demand-side uncertainties. *IEEE Trans. Power Syst.* **2016**, *31*, 2481–2490. [\[CrossRef\]](#)
89. Kopsidas, K.; Kapetanaki, A.; Levi, V. Optimal Demand Response Scheduling with Real Time Thermal Ratings of Overhead Lines for Improved Network Reliability. *IEEE Trans. Smart Grid* **2016**, *8*, 2813–2825. [\[CrossRef\]](#)
90. Xu, Q.; Ding, Y.; Zheng, A. An Optimal Dispatch Model of Wind-Integrated Power System Considering Demand Response and Reliability. *Sustainability* **2017**, *9*, 758. [\[CrossRef\]](#)
91. Gonzalez-Cabrera, N.; Gutierrez-Alcaraz, G. Nodal user's demand response based on incentive based programs. *J. Mod. Power Syst. Clean Energy* **2017**, *5*, 79–90. [\[CrossRef\]](#)
92. Teh, J.; Ooi, C.A.; Cheng, Y.H.; Zainuri, M.A.; Lai, C.M. Composite Reliability Evaluation of Load Demand Side Management and Dynamic Thermal Rating Systems. *Energies* **2018**, *11*, 466. [\[CrossRef\]](#)
93. Li, W. *Reliability Assessment of Electric Power Systems Using MONTE Carlo Methods*; Springer Science & Business Media: Berlin, Germany, 2013.
94. Safdarian, A.; Degefa, M.Z.; Lehtonen, M.; Fotuhi-Firuzabad, M. Distribution network reliability improvements in presence of demand response. *IET Gener. Transm. Distrib.* **2014**, *8*, 2027–2035. [\[CrossRef\]](#)
95. Safdarian, A.; Fotuhi-Firuzabad, M.; Lehtonen, M. Benefits of demand response on operation of distribution networks: A case study. *IEEE Syst. J.* **2016**, *10*, 189–197. [\[CrossRef\]](#)
96. Nojavan, S.; Majidi, M.; Esfetanaj, N.N. An efficient cost-reliability optimization model for optimal siting and sizing of energy storage system in a microgrid in the presence of responsible load management. *Energy* **2017**, *139*, 89–97. [\[CrossRef\]](#)
97. Awad, A.S.; El-Fouly, T.H.; Salama, M.M. Optimal ESS allocation and load shedding for improving distribution system reliability. *IEEE Trans. Smart Grid* **2014**, *5*, 2339–2349. [\[CrossRef\]](#)

98. Zeng, B.; Wu, G.; Wang, J.; Zhang, J.; Zeng, M. Impact of behavior-driven demand response on supply adequacy in smart distribution systems. *Appl. Energy* **2017**, *202*, 125–137. [[CrossRef](#)]
99. Nosratabadi, S.M.; Hooshmand, R.A.; Gholipour, E.; Rahimi, S. Modeling and simulation of long term stochastic assessment in industrial microgrids proficiency considering renewable resources and load growth. *Simul. Model. Pract. Theory* **2017**, *75*, 77–95. [[CrossRef](#)]



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).