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Evolving practice of demand-side management

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Abstract The concept of demand-side management (DSM) was invented in the late 1970s along with the development of many of the frameworks in use to plan and implement it in the years immediately following. It was originally referred to as demand-side load management. It is generally defined as the planning and implementation of those activities designed to influence consumer use of electricity in ways that will result in changes in the utility's load shape—i.e., changes in the time pattern and magnitude of a utility's load. This paper describes the evolution it has undergone since its invention and some likely changes ahead. DSM largely originated in the U.S., but is practiced in various forms through the world today. This paper uses U.S. data as examples.

Keywords Demand-side management (DSM), Demand-side load management, Load management, Energy efficiency, Demand response (DR)

1 Introduction

Principal programs and activities considered to be part of the demand-side management (DSM) tool kit are those which involve a deliberate intervention in the market place so as to alter the consumers' purchase pattern of electricity resulting from either the adoption and use of certain end-use technologies or modifications in the consumer's basic behavior in electricity utilization [1].

DSM evolved during the 1970s as economic, political, social, technological, and resource supply factors combined to change the electricity sectors' operating environment and its outlook for the future. Ever since then there have been staggering capital requirements for new plants, significant fluctuations in demand and energy growth rates, declining financial performance of electric utilities, power producers and energy service providers, and regulatory and consumer concern about rising prices [2]. DSM has been viewed as an effective way of mitigating these risks when it was invented and still viewed so today.

2 DSM framework

During the last four decades, utilities, government entities and other electricity industry stakeholders were discovering the importance of influencing consumers purchase of energy-consuming devices and appliances and their behavior in the utilization of those devices. However, in the 1970s most practitioners generally looked upon a host of options independently without a holistic view of their impact. Utility planners often studied various customer programs or technology options independently from one another assessing options like time-of-use pricing one day and thermal energy storage (TES) another—each study done separately without regard for a systematic way to look at load shape changes and the associated costs and benefits to both the electricity consumers and their suppliers from potential programs and activities.

The DSM framework suggested a logical approach which asked these key questions:

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1) Considering the current set of resources available or under consideration—what changes in the purchase pattern of demand from consumers would be of benefit to them and to suppliers?
2) Which end-use technologies or changes in consumer behavior are likely to yield those changes?
3) What market implementation methods would be needed to influence consumer preference and behavior to produce the desired result?

The basic concept of managing the demand for electricity to match the supply at hand is not new. Efforts aimed at influencing the types of end-uses and their operation is as old as the industry itself. Virtually the only load in New York City's Pearl Street Generating Station in the 1890s was night-time lighting. In response, Edison hired personnel to promote the daytime use of electricity. Another early attempt to manage the demand for electricity was to use price as an incentive. As the industry continued to evolve, alternative technologies like storage water heating, either controlled remotely or by time clocks began to appear. The term "load management" was used in these early years to describe these activities.

3 DSM technologies

Bundles of DSM technologies can be grouped by their potential change in load shape which would improve cost or performance in some way. Six bundles were considered to be part of the original DSM concept.

3.1 Peak clipping technologies

Peak clipping technologies are those which cause a reduction in coincident demand at the time of system peak. Typically it is implemented by using direct load control (DLC) of appliances or devices by consumer action or by use of automated controls or communications.

3.2 Valley filling technologies

Valley filling technologies are those which increase the demand for electricity during off-peak daily or seasonal periods considered "valley" or low periods of demand. Typical technologies employed to fill valleys are electric vehicles, battery energy storage as well as new space heating, cooling or domestic water heating integrated with storage or designed so as not to operate during on-peak periods.

3.3 Load shifting technologies

Load shifting technologies are those which facilitate moving or shifting existing loads to off-peak periods. Technologies involved often use process control to modify industrial operations or use electric energy storage or thermal energy storage for space heating, cooling or domestic water heating.

3.4 Energy efficiency technologies

Energy efficient technologies are those which reduce overall energy needs while maintaining or improving the quality of energy services. Energy efficient technologies are high efficiency appliances or devices or involve the use of advanced building envelopes, fenestration, controls or ventilation.

3.5 Electrification technologies

Electrification technologies include all of those which involve the conversion of non-electric end-uses to electricity. These technologies can include those which enable the conversion of existing fossil-fueled applications or the addition of electric end-use appliance where fossil fuel might otherwise have been employed. Examples include the use of electric space heating or water heating instead of natural gas or fuel oil; electric transportation or materials handing instead of gasoline or diesel.

3.6 Flexible load shape technologies

Flexible load shape technologies are those which enable a truly integrated grid by facilitating dynamic control and response to both the consumer's load and to their use of distributed generation and storage. Control can be direct or through autonomous agents or by the use of controllable appliances or energy management systems.

4 DSM programs and activities

As the industry's interest in managing demand increased and the acceptance of DSM as a unifying umbrella to house programs or activities which could manage demand increased as well, it became clear that there were seven generic actions, taken together or independently which could have the greatest impact in actually effecting the deployment of DSM. These included: 1) alternative electricity pricing, aka—innovative rates; 2) direct and indirect financial incentives; 3) consumer education; 4) direct customer contact; 5) trade ally cooperation; 6) advertising and promotion; and 7) building codes and appliance efficiency standards. These seven, taken in combination with the appropriate technologies, define the type of generic DSM programs or activities being implemented. The most prevalent programs and activities referred to in the literature are: load control; thermal energy storage and dual-fuel heating (DFH); innovative rates; energy efficiency; demand response (DR); and electrification.

4.1 Load control

Load control, sometimes referred to as direct load control programs were the first type of DSM programs to appear in the U.S. During the early 1950s a number of U.S. Rural Electric Cooperatives installed ripple-type load control systems on consumer electric water heaters. Ripple systems employed a method of communication which enabled the utility to slightly disrupt the AC waveform as a means by which a signal could be sent to disconnect and reconnect the appliances [3]. These Rural Cooperatives typically purchased their wholesale electricity for resale from larger utilities under tariff arrangements which included charges for energy and peak demand. Thus, they often had substantial incentives to reduce peak demand by load control. These programs evolved during the 1960s and then included electronic control. For example, in 1968 Detroit Edison replaced water heater time clocks with a radio system. Others followed, including Buckeye Power in 1973, Arkansas Power and Light in 1976 and various Kansas and Nebraska utilities utilizing irrigation control in the years immediately following.

Surveys conducted in 1985 revealed that a total of 259 load control projects conducted by 227 electric utilities were reported in the U.S. [4]. These load control activities consisted of three types: direct load control, distributed control and load control. In a 1985 Electric Power Research Institute (EPRI) survey the electric water heater was identified as the most commonly controlled load with over one million units reported as being under control. Central air-conditioners were the second most commonly control load with a reported 913413 residential and 40238 commercial units under control. In addition, 148756 space heating, 311763 pool pumps and 17064 irrigation units were also reported as being under control.

4.2 Thermal energy storage and dual-fuel heating

Nearly paralleling the development and adoption of load control were efforts aimed at changing the characteristic of the end-use loads themselves. These efforts were focused primarily toward thermal energy storage space heating and dual fuel heating systems [5]. American Electric Power Company (AEP) pioneered thermal energy storage systems in the U.S. by commercializing and promoting a central storage furnace developed by Creda Electric Ltd. of the UK. Other utilities including Green Mountain Power and Central Vermont Public Service followed suit by offering rate structures and promotional programs intended to accelerate adoption of these technologies. Dual-fuel heating was popularized by Minnkota Power Cooperative and consisted of large, well-insulated water heaters which could use electricity during off-peak periods and fossil fuels at other times.

By 1985, a total of 172 thermal energy storage and dual-fuel heating projects were underway by 109 utilities involving over 68000 installations. In the decades which followed these projects declined in popularity.

4.3 Innovative Rates

Among the most important element of any utility DSM programs are alternative or innovative rates. These rates often form the basis for offering incentives to consumers to change their pattern of electricity demand. In addition, they often provide the stimulus for investing in DSM technologies. A major survey conducted in 1984 provided an excellent snapshot of the evolution of alternative pricing mechanisms [6]. A total of 220 major electric utilities were surveyed with 105 reporting some form of time-of-use rates in their portfolios. In addition, 85 utilities reported to have deployed some form of innovative or curtailable rate. The 1984 survey began to see the emergence of other alternative rates including inverted block, residential demand and special purpose incentives.

4.4 Energy efficiency

It is now common practice for most utilities to include energy efficiency-type DSM in their portfolios. These are often funded by ratepayer-based programs or other mechanisms, in order to reduce energy consumption over what it would have been without DSM. Upward trends in energy efficiency program expenditures signal downward pressure on electricity demand. The energy intensity of end-uses will reduce further as a result of increased spending by electric utilities on DSM programs and activities. For example, utility spending in the U.S. and Canada on energy efficiency programs has risen to \$9.9 billion in 2014 [7].

A recent EPRI study estimates that these types of energy efficiency programs have the potential to reduce U.S. electricity consumption in the year 2035 by 488 TWh to 630 TWh or between 11% and 14% [8]. Therefore, energy efficiency programs have the potential to reduce the 0.72% annual growth rate in electricity consumption forecasted in the AEO2012 Reference case between 2012 and 2035 by 51% to 72%, to an annual growth rate of 0.36% to 0.20%. These estimated levels of electricity savings are achievable through DSM programs consisting of voluntary energy efficiency programs implemented by electric utilities or similar entities. These EPRI estimates do not assume the enactment of new energy codes and efficiency standards beyond what is already in law. EPRI's experts acknowledge that more progressive building energy codes and appliance efficiency standards would yield even greater levels of electricity savings.

The Annual Energy Outlook (AEO) estimated that peak electricity demand in the U.S. was projected to be 595 GW in 2012 and expected to increase to 714 GW by 2015, reflecting a 0.8% compound annual growth rate. The same EPRI study estimated that DSM programs in energy efficiency had the potential to reduce coincident summer peak demand by 79 GW to 117 GW. This represents a range of 10% to 14% in 2035 by the use of voluntary DSM programs.

The energy efficiency measures included in EPRI's analysis that were typical of other studies of energy efficiency potential and included the key measures listed in Table 1.

Each technology category can have an array of DSM programs used individually or in combination to promote these efficient technologies. For example, respondents in a 1987 survey of utility lighting programs indicated that they used lighting programs to meet DSM objectives [9]. Five types of utility lighting programs were being pursued as follows:

1) Energy-efficient lighting overall
2) Outdoor security lighting
3) Customer education
4) Street lighting
5) Special activities

Within these programs, the following types of measures and equipment were being advocated:

1) Conversion from incandescent and standard fluorescent lamps to high-efficiency fluorescent lamps
2) Conversion to high efficiency ballasts
3) De-lamping
4) Use of reflectors
5) Daylighting
6) Occupancy sensors and daylight sensors
7) Conversion from mercury to high-pressure sodium or metal halide

Table 1 Summary of key energy efficiency measures typically included in energy efficiency studies

No.	Energy efficiency measure categories
1	Efficient air conditioning
2	Efficient space heating (heat pumps)
3	Efficient water heating (e.g., heat pump water heaters)
4	Efficient appliances (refrigerators, freezers, washers, dryers)
5	Efficient lighting
6	Programmable thermostats
7	Efficient I.T. equipment (e.g., computers and power supplies)
8	Infiltration control
9	Building insulation
10	High efficiency windows
11	Energy management systems
12	HVAC maintenance

The United States Department of Energy (USDOE) estimates that the incremental savings from energy efficiency ranges between 25 TWh and 27 TWh per year (see Table 2), with an accompanying peak demand savings of as much as 20 GW, depending on weather conditions.

Table 2 lists the expected reduction in energy and peak demand for U.S. residential, commercial, industrial, and transportation sectors as well as the incentives and other costs expended to achieve those results [10]. As shown, the total energy savings in 2013 and 2014 for all sectors ranged between 24681523 MWh and 26465221 MWh with accompanying peak reductions of 19599 MW and 6517 MW. These reductions came at a cost of between 2872171 and 3411034 thousand dollars for incentives and 1945877 and 2209148 thousand dollars for other incentives.

4.5 Demand response

The U.S. Energy Independence and Security Act of 2007 popularized the term demand response and generally defined it as including programs and activities which reduce peak demand by the use of dynamic pricing, advanced metering and enabling technologies. The U.S. Energy Information Administration estimates that over 9 million customers are enrolled in demand response programs (2014) yielding an actual peak demand savings of 12700 MW (see Fig. 1) [10]. The U.S. Federal Energy Regulatory Commission (FERC) has estimated that the potential for demand response is such so as to reduce peak demand in 2019 by as much as 150 GW [11].

Some industry practitioners have incorrectly offered that "traditional DSM programs are slowly getting replaced with demand response programs" [12]. Demand response is a characterization of certain DSM programs which specifically reduce peak demand. DSM is a much broader concept which includes demand response. Growth of demand response programs of both PJM and the New York Independent System Operator (NYISO) serve as an excellent example of the success or demand response-type DSM. With the expansion in New York and the PJM area, consumers with the appropriate DSM technology in place have the opportunity to get paid by the relevant ISO in the same way that an electricity generator gets compensated. Typically, demand response consumers use distributed generation or energy management control strategies to

Table 2 Energy efficiency category

Sector	Energy savings (MWh)		Peak savings (MW)		Incentives (thousand dollars)		All other costs (thousand dollars)	
	2013	2014	2013	2014	2013	2014	2013	2014
Resident	11031419	11442191	6812	3031	1252085	1522335	1015842	1088970
Commercial	10478997	11928895	11319	2920	1274406	1561408	750299	911968
Industrial	3141213	3074819	1463	564	345676	327227	179719	208096
Transportation	29894	19316	5	2	5	64	33	122
Total	24681523	26465221	19599	6517	2872171	3411034	1945877	2209148

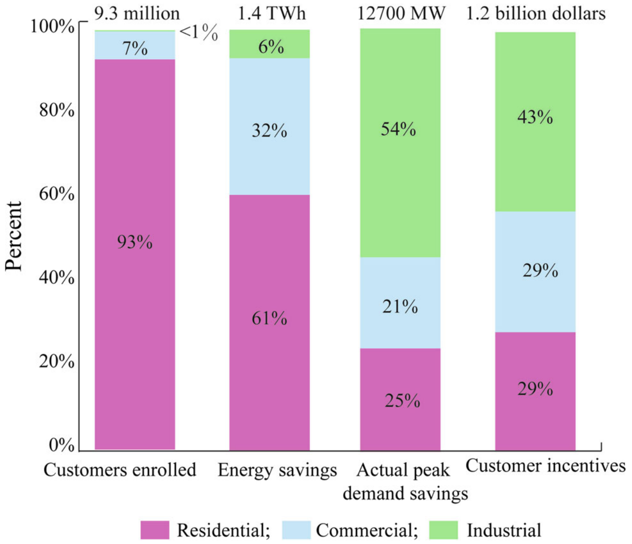


Fig. 1 Sectoral composition of U.S. demand response programs (2014)

reduce their demand in price signals provided by the ISO. PJM’s demand response programs engaged 4500 MW of emergency demand response in 2008 and 3250 MW in economic demand response [12].

4.6 Electrification

Electrification is referred to in one of two related ways. Historically it is a term often used to describe the process of enabling consumers who do not have electricity to gain access. In that context it most typically refers to places like India, China, Africa and Brazil where there are millions of citizens who do not have electricity. In the context of traditional DSM, it includes the adoption of new uses of electricity and the installation of electric devices in places where fossil-fueled devices would otherwise have been used.

There is a potential to reduce CO_2 emissions between 114 and 320 million metric tons per year of CO_2 in 2030 due to electrification involving the expanded end-use applications of electricity [13]. More progressive codes and standards and a less carbon-intensive generation mix would yield even greater levels of CO_2 emissions reductions. Figure 2 graphically depict the impacts of the electric end-use technologies on primary energy use and CO_2, respectively. The values are expressed in terms of the cumulative technical potential impacts between 2009 and 2030. In all three sectors, heat pumps are the technology with the greatest promise for saving energy and reducing CO_2 emissions. In the industrial sector, electric arc furnaces have a significant potential for beneficial impacts as well. In addition, electrolytic reduction, electric induction melting, and plasma melting also show promise. Under a less carbon-intensive future generation mix, more technologies would cross the line and become favorable in regards to saving energy and reducing emissions.

In both the residential and commercial sectors, the end-use areas with the most potential for beneficial impacts are space heating and then water heating. Clothes drying (residential) and space cooling (commercial) also exhibit

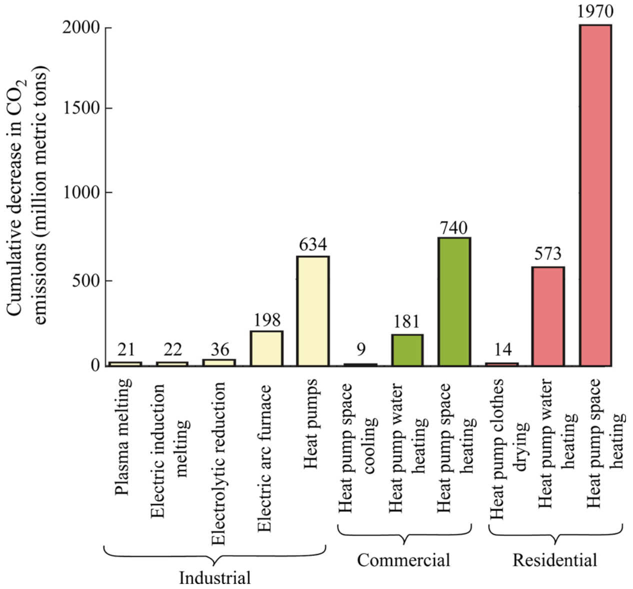


Fig. 2 Technical potential: cumulative decrease in energy-related CO_2 emissions in the U.S. between 2009 and 2030 by sector and efficient electric end-use technology

potential. In the industrial sector, process heating is the predominant end-use area showing potential, followed by space heating.

One major new electrification appliance that has begun to populate the residential landscape is the plug-in electric vehicle (PEV). The PEV market includes over a dozen passenger vehicle models, with more expected in the years ahead. It has been estimated that new vehicle market share could approach 30% by 2030, resulting in 9 million vehicles sold by 2030 [13]. A recent study by the EPRI and the Natural Resources Defense Council (NRDC) estimates that while in the U.S. only 1% of vehicle miles driven today are from electric vehicles, that figure could reach as high as 53% by 2050 resulting in a 48% to 70% reduction in emissions [14, 15]. Many utilities are promoting PEV adoption as a means to effect electrification.

DSM programs which promote off road electric transportation are another new use with substantial potential to increase electricity demand. As shown in Table 3 [11], electricity use increases are expected to be greatest for industrial equipment, lawn and garden equipment, and shore side power.

The net impact of new uses, PEVs and data centers estimated in 2030 are listed in Table 4.

5 Next steps in the evolution of DSM

There are likely to be more changes in today's power system in the next ten years than there have been in the last 100. In large measure this results from the dramatic changes in the cost and performance of distributed energy resources (DERs) as well as other distributed generation, storage and energy utilization devices and appliances. At no time since the first power systems were invented and deployed has there been such a variety of new energy technology available or waiting in the wings. These have potential to fundamentally and profoundly change the generation, delivery and utilization of electricity and related electric energy services.

5.1 Integrated grid

As these changes evolve, the best societal option will increasingly be a truly dynamic power system. This approach enables resources and technologies to be deployed operationally to realize all potential benefits. It requires a robust and modern grid characterized by connectivity, rules enabling interconnection and innovative rate structures that enhance the value of the power system to all consumers [16]. DSM will be increasingly important in enabling a marriage between these various technologies and systems so as to enhance the utilization of the power system and enable increased reliability and enhanced consumer choice while maximizing the penetration of distributed energy resources including photovoltaics, energy storage and efficient buildings, appliances and devices. DSM can support the evolution of roles for suppliers, producers, consumers, utilities and regulators in this evolving world.

Table 4 Total impacts of new uses of electricity in the U.S. in 2030

Item	Net impact (TWh)
New uses	991
PEVs	20–96
Off-road equipment	18–54
Data centers	340
Total	1369–1481

Table 3 Estimated impact of electrification in the U.S. from various devices

Equipment type	Electricity demand in 20 years (GWh)^{1,2,3}
Agricultural pumps	400–600
Aircraft gate electrification	80–120
Airport ground support equipment	200–900
Cargo handling equipment (cranes, yard trucks)	1000–2000
Harbor craft	900–1700
Industrial equipment (forklifts, transportation refrigeration units, sweepers)	6300–27000
Lawn and garden equipment	2900–11000
Ship shore side power	4400–6600
Switching locomotives	400–900
Recreational equipment (all-terrain vehicles, off-road motorcycles, golf carts, specialty carts)	1200–2400
Total	18000–53000

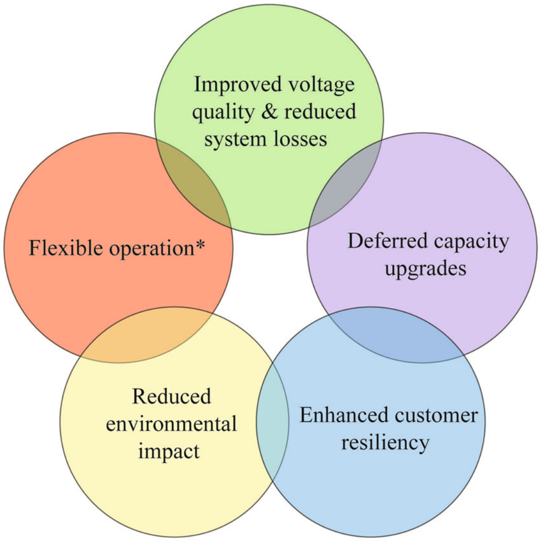
Note: 1. For lower 48 states, does not include Hawaii or Alaska; 2. For equipment electrified after 2010; 3. Year 2030 estimates.

Figure 3 illustrates the primary benefits of a truly integrated power system utilizing all aspects of DSM [16].

The Solar Energy Industries Association recently reported that the U.S. solar market remains what they refer to as “on track” for a record-breaking year, with 1361 MW installed during the third quarter of 2015 and 4.1 GW installed during the first three quarters of 2015. Much of this is new solar power generation installed on residential buildings [17]. These installations are often funded by third parties and contracted for by consumers through a variety of purchase power agreements. The lowest cost and most effective power system can no longer be configured solely by combinations of central station power generation knitted to customers by power delivery systems. Today and increasingly into the future, society’s needs for reliable, affordable and sustainable electricity can best be met by an optimal combination of distributed generation, distributed energy storage, energy efficiency and new uses of electricity integrated with central generation and bulk system storage.

As these distributed solar installations proliferate, the value of DSM will evolve, as will the DSM market participants. DSM incentives targeted toward consumers in order to influence the pattern and amount of electricity usage will still be valuable, but will change in how they are offered.

For example, Salt River Project (SRP), an electric utility in the Phoenix, AZ area, faced with substantial increases in photovoltaic system adoption by its consumers, has modified how it compensates customers who produce excess energy. SRP’s current tariffs allow consumers with excess photovoltaic power generation to sell those kilowatt-hours to SRP at a flat rate which does not vary by time of day. Rather than pay a flat rate, SRP’s plan encourages the use of emerging storage and control technologies so as to reduce the demand on its system during critical periods (www.srpnet.com). A further example is the City of Austin, Texas. In the so called Pecan Street Project, Pecan Street Inc., a research and development organization (www.pecanstreet.org) learned through experimentation that the kilowatt-hours generated from homes with west facing solar panels were more valuable than those generated from homes with south facing roofs. The energy generated from west-facing panels occurred later in the day when the sun’s arc was westward leaning generating energy which could displace more expensive central generation alternatives. In this example, as DSM evolves, incentives like those for solar energy will need to be tied to the time varying benefit of load shape changes. If the displaced central generation is more expensive later in the day—then utilities can pay more for the replacement. Likewise, if the displaced generation is less costly—then the utilities will pay less. As power systems evolve, so will the focus of DSM—but with the same overall objective of maximizing the benefits of electricity to consumers and society.



*Enhances reliability and impacts distribution operations, DER integration, minimizes re-conductoring, provides ancillary services (frequency response, non-spinning reserve and demand response)

Fig. 3 Primary benefits of an integrated power system

5.2 Load control-type DSM of the future

As DSM evolves, load control-type DSM would be increasingly used to enable coordinated control of high-penetration PV systems as illustrated in Fig. 4 [18]. Here remotely controlled advanced inverters are used to enhance voltage control and balance the ratio of real and reactive power needed to reduce losses and improve system stability.

Figure 4 illustrates how PV systems with advanced inverters can offer reactive compensation. Key to this

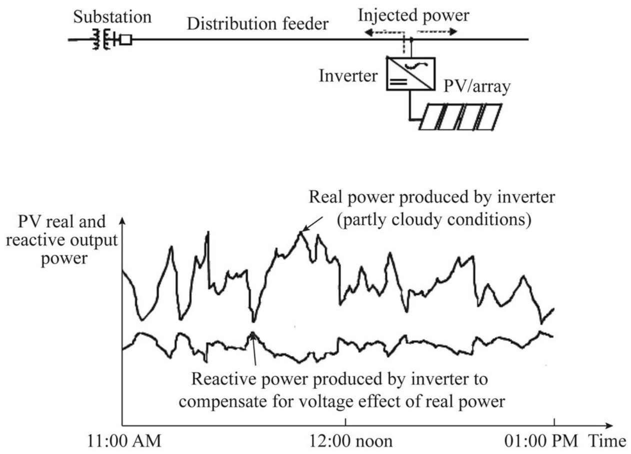


Fig. 4 Advanced inverter for reactive compensation

ability is both the deployment of advanced inverters and the availability of a load control-type DSM utilizing communications with a distribution management system. This type of control also enables participation in demand response programs including various customer notification schemes, interruptible tariffs, direct load control, real-time pricing, and critical peak pricing. This control scheme can also enable higher penetration of PV on distribution feeder without necessary re-conductoring or reinforcement.

5.3 Transactive energy

Part of the evolution of DSM may be to stimulate markets for DSM. In DSM markets, incentives can be provided by utilities and market operators like Independent System Operators which encourage third parties to bring DSM opportunities forward. Some in the industry have called this change in the marketplace for electricity "transactive energy". Transactive energy envisions a market of multiple dimensions wherein consumers, utilities and providers of all types can transact with anyone in the energy marketplace. Several states in the U.S. are debating how, if at all, this concept can be used as the basis for tomorrow's energy system. For example, in New York, a regulatory proceeding has been launched referred to as "Reforming the Energy Vision" which is investigating a variety of new transaction arrangements. Concepts like these will assure that DSM remains a viable option in developing the landscape for tomorrow's power system. However, without orchestrating a careful transition from the existing financial arrangements which utilities enjoy, unleashing transactive energy can place a great deal of risk on the ability to continue to support the existing power delivery infrastructure.

6 Conclusion

DSM is an effective way of matching the demand for electric energy services with available central and distributed resources. Gradually since the 1970s interest in the portfolio of DSM options has expanded. Deploying all aspects of DSM remains an effective means of expanding the effectiveness and functionality of power systems. DSM will continue to be an important option as power systems continue to evolve.

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