

## Investigating the Effect of Demand Side Management on the Power System Reliability

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### **Abstract**

*In electric power systems, the generated power should be equal with the demand and power of network is mainly controlled through generation system. In such operation, the demand is satisfied through changing the generated power and afterward, the safe operation of power system is reached. But during recent years, a new concept has been developed in electric power systems namely demand side management (DSM). DSM is the modification of consumer demand for energy through various methods such as financial incentives and education. Usually, the goal of demand side management is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. One of the important models of DSM is interruptible loads. Interruptible loads are the right for an electricity utility to interrupt supply to a customer, typically during a system emergency, to relieve short term network constraints up to a couple of hours. Interruptible loads can be deployed in one of two ways. The network operator gives notice of an interruptible load event to the customer, then relies on the customer to reduce their electricity usage; or unilaterally interrupts supply to the customer. In this paper, the effect of interruptible loads on the power system reliability is investigated. A multi machine power system is considered as cases study. Simulation results show the great effects of interruptible loads on the power system reliability.*

**Keywords:** Demand Side Management, Interruptible Loads, Power System, Reliability

### **1. Introduction**

Power system reliability has always been discussed as an important topic in electric power systems. In this regard, many studies have been carried out to investigate the effects of reliability on the system performance [1-10].

Some applications of reliability studies about renewable energies in electric power systems are as follows; Reliability assessment of photovoltaic power systems is presented by [1]. Where, a review of current status and future perspectives is presented. Paper [9] addresses a reliability centered maintenance optimization for power distribution systems. A review on reliability assessment for wind power is presented by [2].

In paper [5], an original non-sequential Monte Carlo simulation tool is developed. This tool permits to compute the optimal dispatch of classical (coal, oil, etc.) thermal generation in order to minimize polluting gases (NO<sub>x</sub>, CO<sub>2</sub>, etc.) emissions in presence of wind power and under constraints. The proposed solution can be a useful tool for electrical system operators in order to dispatch the polluting thermal units under cost, reliability, emissions, fluctuating wind power and unexpected outages constraints. Some other research works based on the Monte Carlo simulation method have been well reported in [6-7].

In paper [11], operating benefits from demand-side load management are evaluated for a Proton Exchange Membrane (PEM) Fuel Cell Power Plant (FCPP). For reliability modeling and evaluation of the PEM FCPP, a state-space generation model for a stand-alone PEM fuel cell that calculates the system availability and the expected energy not supplied (EENS) index has been developed. A systematic technique and detailed computer simulation software for a stand-alone PEM fuel cell station reliability assessment have been built. The suggested technique can be used for practical engineering applications to provide information for stand-alone FC generating station planning, design, and operation. The simulation results are obtained using the MATLAB software for a 5 kW stand-alone PEM fuel cell that supplies a typical residential house.

In this paper, the effect of interruptible loads on the power system reliability is investigated. A multi machine power system is considered as cases study. Simulation results show the great effects of interruptible loads on the power system reliability.

## **2. Demand Side Management**

Demand side management (DSM) is the use of financial incentives, education, or other programs to shift peak energy loads to other times, cut the peak load, or reduce the total load by increasing energy efficiency [12]. The term DSM was coined, and programs began, in California due to the energy crises of 1973 and 1979. The initiatives to achieve DSM are often intertwined, but usually include one or all of the following [12]:

### **2.1. Direct Load Control and Demand Response**

Direct load control (DLC) and demand response (DR) have the same goal of switching off non-essential devices during periods of high demand. In DLC the electricity utility can exercise control in periods of high demand over devices that consumers have volunteered to outfit with a communicating controller, with the incentive of paying reduced energy rates. Conversely, in DR, the consumer is expected to control the demand manually, by responding to pricing initiatives or smart meters. Examples include [12]:

- The Queensland Government's Demand Management Program<sup>1</sup> fits energy-saving devices to appliances like air conditioners, pool pumps and hot water systems to enable remote cycling over the few hours of peak demand.
- Toronto Hydro's 'Peak saver' initiative for furnaces and air conditioners which pays consumers to use smart thermostats in their homes. The objective of the scheme was to trim 2 GW off the peak demand that pushed the peak demand up to 27 GW for only 32 hours of the year. The initiative avoided the need to install the additional 2 GW capacity.<sup>2</sup>
- Florida Power and Light (FPL) has successfully implemented direct load programs because of their multi-pronged approach; marketing communications, pricing incentives, and customer education. The FPL regulatory filings have consistently shown that installing and operating their entire DMS program costs 20% to 30% less than building and operating new generating units.<sup>3</sup>

### **2.2. Interruptible Loads**

Interruptible loads are the right for an electricity utility to interrupt supply to a customer, typically during a system emergency, to relieve short term network constraints up to a couple of hours. Similar to Direct Load Control, they apply on a much larger scale than individual pieces of equipment or appliances outfitted for DLC. Interruptible loads can be deployed in one of two ways. The network operator gives notice of an interruptible load event to the customer, then relies on the customer to reduce their electricity usage; or unilaterally interrupts supply to the customer [12].

Good examples of interruptible loads are:

- Florida has operated a voluntary Interruptible Service Program since 1996, available to commercial and industrial customers with an average demand over 500 kW. The utility, Florida Power and Light (FPL) operating under Progress Energy Florida (PEF), has remote control over the customer's supply circuit breaker. Customers are paid a credit per kW of reduced demand below their normal load factor. Using a portfolio of DSM programs, including interruptible rates for large power customers and a predominantly residential load-control program, FPL and its customers had successfully reduced demand for energy by 3463 MW as of 2004. This reduction had allowed FPL to avoid building approximately ten new 400 MW power plants. This prevented blackouts, but also allowed FPL to sell energy to other utilities within Florida when they needed additional power to meet their capacity needs.<sup>4</sup>
- In Spain the transmission system operator Red Eléctrica de España (REE) has been running an interruptible load program since 1983. The customers, who range from metal industries to airports, receive a discounted electricity bill in return for signing up to one of the following Load Interruption Contracts, which differ by interruption duration and warning time. An example of the impact is the 3,800 MWh shed during a particular load interruption which saved the utility some €305,000.

### 2.3. Pricing Initiatives and Smart Meters

The true cost of energy is not consistent during each day, because of the fluctuations in supply and demand. Yet most consumers pay a standard price, which provides no incentive for users to reduce their power during times of high demand, and ultimately costs the public through increased government spending to provide generation capacity for those few days of peak demand each year. Pricing initiatives make consumers pay a truer price for their energy, reflective of the real value of the energy at that time of the day or year. Pricing initiatives usually require users to have Smart Meters installed, which some utilities will subsidize the cost of in order to encourage more customers to switch. Smart meters also provide end-users with detailed information about their energy use patterns, which could be used to identify energy, cost and carbon savings. After California's 2001 energy crisis the California Energy Commission created the Critical Peak Pricing tariff for large industrial and commercial energy consumers. This optional program charged higher energy prices (up to 10 times the normal price) during up to 12 "Critical Peak Pricing Days" each summer. The customers were warned the day before a CPP day. In exchange the customers received smart meters and discounted electricity rates (up to 10% cheaper) during all other times of the summer. After four years of experimentation, the French government launched the optional Tempo nationwide tariff program to smooth both the annual and daily load curves, reducing marginal generation and network costs. The customers can choose to stay on a flat-rate base option, a peak/off-peak dual rate system, or the complex Tempo option with pricing up to ten times higher on critical days than on the extremely-cheap non-critical days. Customers who choose Option Tempo are informed each night about the color for the next day on their control unit. The results have been tremendous, reducing electricity consumption on critical days by 45% compared with non-critical, saving Tempo customers on average 10% on their bills, achieving 90% positive feedback from users, and has become the option chosen by 20% of all electricity consumers. In Western Australia, Synergy offers variable pricing options for customers under the Smart Power program, offering four pricing rates based on time of the week and specific month. The peak rate is up to 4 times higher than the lowest rate, allowing the customers to decide when to operate appliances, to allow them to save money. The customers are charged a one-time fee to install the Smart Power meter [12].

### 3. Test System

In this paper, a standard six bus power system is considered as case study. Figure 1 shows the proposed test system. The system data are given from [14] and shown in Tables 1-2.

Table 1. The generation and load data

Bus	Type	$P_D$	$Q_D(\text{MVar})$	$P_G^{\max}$	$P_G^{\min}$	$Q_G^{\max}$	$Q_G^{\min}$
1	VΘ	80	16	150	0	48	-10
2	PQ	240	48	-	-	-	-
3	PV	40	8	360	0	101	-10
4	PQ	160	32	-	-	-	-
5	PQ	240	48	-	-	-	-
6	PV	0	0	600	0	183	-10

Table 2. The transmission lines data

Bus From	Bus To	$r_{ij}[\text{p.u.}]$	$x_{ij}[\text{p.u.}]$	$b_{ij}^{\text{sh}}[\text{p.u.}]$	$S_{ij}^{\max}[\text{MVA}]$
1	2	0.040	0.400	0.00	120
1	4	0.060	0.600	0.00	100
1	5	0.020	0.200	0.00	120
2	3	0.020	0.200	0.00	120
2	4	0.040	0.400	0.00	120
2	6	0.030	0.300	0.00	120
3	5	0.020	0.200	0.00	120
3	6	0.048	0.480	0.00	120
4	6	0.030	0.300	0.00	120

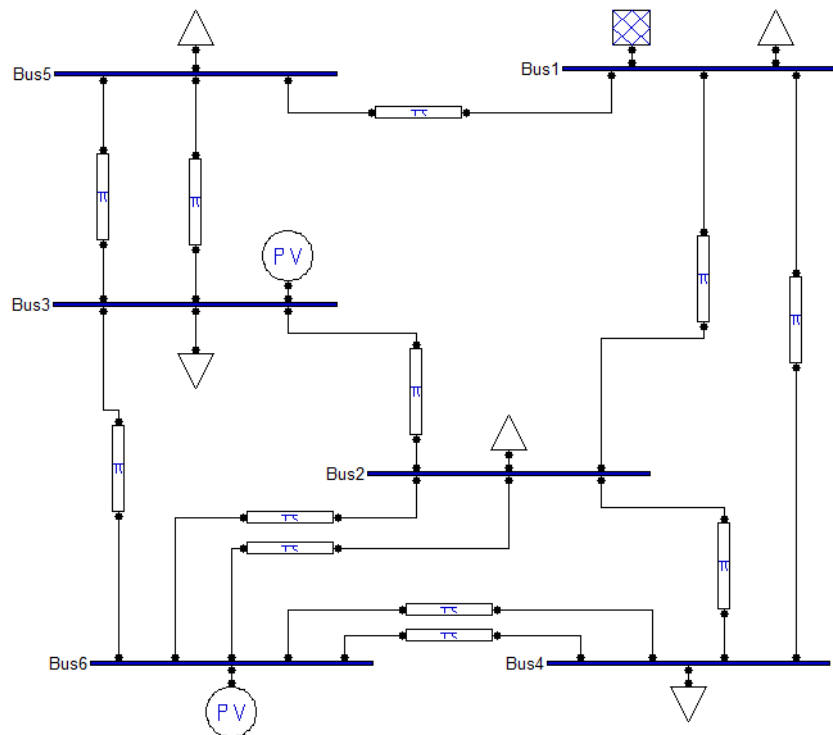


Figure 1. Six bus test system

#### 4. Reliability Evaluation based on the Monte-Carlo Simulation

Monte-Carlo simulation is a well-known method to evaluate the reliability in electric power systems. This method has been introduced in [15]. Power system indexes such as LOLP and LOLE are calculated based on the Monte-Carlo simulation as follows [15]:

$$\text{LOLP} = N/NS \quad (1)$$

$$\text{LOLE} = \text{LOLP} \times 365 \times 24 \quad (2)$$

Where, NS represents number of all simulation scenarios, N shows number of scenarios in which the load is curtailed, 365 indicates the number of days at one year and 24 shows the number of hours at one day. In the proposed test system, FOR is assumed as 0.03 for all lines and LOLE is simulated as Figure 2. Where, the final values of LOLE is 140 hours/year.

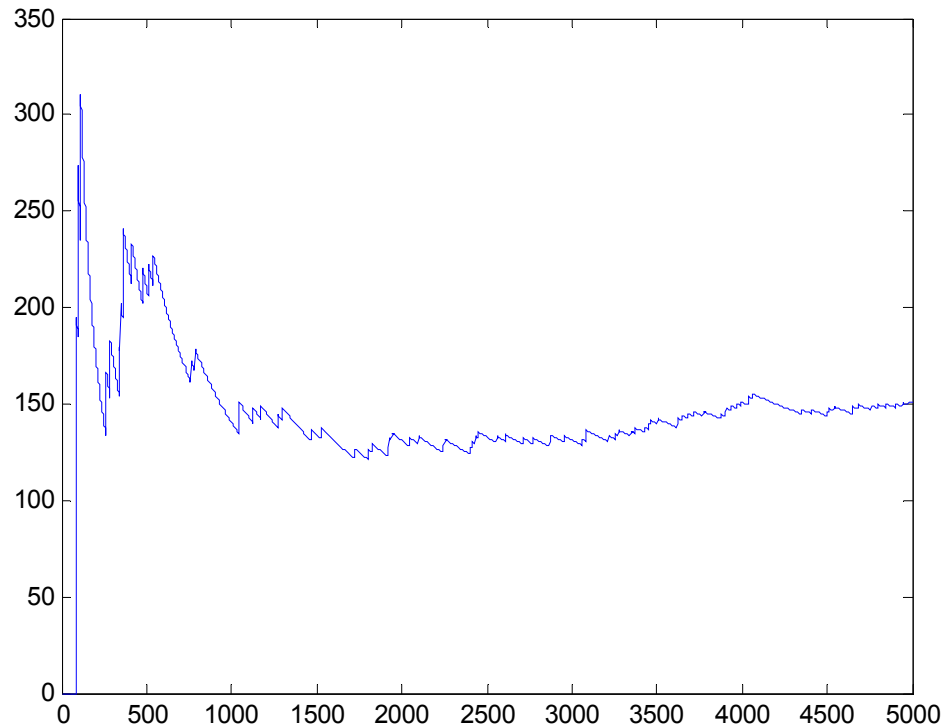


Figure 2. LOLE index for the proposed test system

### 5. Demand Side Management Programs

In this paper, four DSM programs are considered as interruptible loads. Table 3 shows these items. The loads are modeled as constant PQ loads.

Table 3. The DSM programs as interruptible loads

No	Program
1	Curtailing 20% of active power at bus 2
2	Curtailing 20% of active power at bus 4
3	Curtailing 20% of active power at bus 5
4	Curtailing 10% of reactive power at buses 2, 4 and 5

### 6. Simulation Results

In this section, in order to evaluate the effects of DSM programs on the system reliability, LOLE index is assessed following several DSM programs [15]. Table 4 shows the effects of DSM programs on the power system reliability. At case 1, curtailing 20% of active power at bus 2 is considered as DSM program and LOLE following this DSM program is 86.3627 hours per year. At case 2, curtailing 20% of active power at bus 4 is considered as DSM program and LOLE following this DSM program is 83.6655 hours per year. At case 3, curtailing 20% of active power at bus 5 is considered as DSM program and LOLE following this DSM program is 31.3828 hours per year. The effect of reactive power DSMs is investigated at case 4. In such condition, the LOLE index is 88.4964 hours per year.

It is clear that DSM programs significantly influence on the reliability and LOLE index is greatly reduced following DSM programs. The LOLE index is reduced by 32, 30, 76 and 30 percent following programs 1 to 4 respectively. Therefore, the best DSM programs is program 3. Where, the active power at bus 5 is curtailed. In addition, program 4 shows that DSM programs can be carried out based on the reactive powers. In such conditions, it is not required to curtail the load and reactive power can be supplied through locally reactive sources.

The results also show that DSM program at bus 5 is more effective than the other places. This issue is due to the transfer capability of the system toward bus 5 and congested lines at this corridor. However, it can be concluded that DSM program at bus 5 is suggested as the best case for power system operator.

Table 4. Effects of DSM programs on the power system reliability

No	DSM Program (Interruptible loads)	LOLE (h/y)
1	Curtailing 20% of active power at bus 2	86.3627
2	Curtailing 20% of active power at bus 4	83.6655
3	Curtailing 20% of active power at bus 5	31.3828
4	Curtailing 10% of reactive power at buses 2, 4 and 5	88.4964

## 7. Conclusions

This paper presented the effects of DSM programs on the power system reliability. Four DSM programs as interruptible loads were considered. Where, reactive and active loads were included in the DSM programs. The power system reliability was calculated through Monte-Carlo simulation and LOLE index was considered to evaluate the system reliability. DSM programs significantly influenced on the reliability, and LOLE index was greatly reduced following DSM programs. It was also shown that DSM programs can be carried out based on the reactive powers. The proposed method showed a suitable method to denote the best places for DSM programs from view of reliability. In such condition, the power system planner can decide on the DSM programs based on their effectiveness and cost.

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