Load Estimation and Supporting Energy Efficiency in Smart Grids

Hossein Shahinzadeh , Hajar Ghotb

Abstract— Today, the smart grids has gain a special interest in the area of distribution system, so the role of accountability programs in operation and development of distributed systems and also, the optimum benefits of these programs are of special importance. Now more power companies around the world tend to provide more infrastructure which is needed for smart grid as a convenient way to appropriate and effective use of network and solve network problems.The present study first, the structure of the smart grid and the way it engages in smart grid environment is reviewed, then the role of smart grid programs in reducing load and load management is examined. In order to demonstrate the feasibility and effectiveness of the role of smart grid, optimization problem on a distributed network of 33 feeders IEEE with 384 subscribers in different modes of operation, by MATLAB software has been investigated.

Index Terms— Smart Grids, Distributed Network, Dstribution Management System, Load Estimation.

1 Introduction

FACTORS such as increasing electricity demand, shortage of conventional energy sources, government efforts to greater use of renewable resources, etc. has resulted in unaccountability of electricity networks with the current structure in the future.

Smart design is expressed as one of the recent topics in electricity networks, particularly in the distribution field. Although many definitions have been proposed for smart grid , but what is clear is that a smart grid is a network which uses a two-way communication, the latest telecommunication technologies and advanced sensors between components and power system components leading to improved efficiency , improved reliability and security of delivered and used electricity. Improving communication between consumers and producers can lead to more consumer participation in Demand Response Programs and maximum use of distributed generation and renewable energy sources and consequently result in saving investment and operation costs, delays in building new power plants and paving smoothing the network load curve.

So far very diverse research has been conducted in demand response programs , Including benefits and challenges of implementing this program , for Examples the effect these programs on energy market operations and reserve , production of renewable resources and the economic modeling programs.

This study aims to the introduce the smart grids and assesses their role in report the instantaneous power load to the power market and consumer participation in demand response programs and maximum use of distributed generation and renewable energy sources and thus saving on capital costs and operation.

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2 Features & Function of Smart Grid

The basic concept of smart grid is addition of monitoring, analysis, control and communications capabilities to power system for increased efficiency, while simultaneously consumption can be reduced. The smart grids are beneficial, both economically and environmentally. Economically, use of smart grid would reduce consumption through increased system efficiency, Customer Training and participating them in overall performance of the network, and also through the implementation of load management and demand response programs.

With respect to the environment the overall rate of production and emission of carbon dioxide can be reduced by use of smart grid; this reduction is performed through increased management of load and consumption, reducing the production in peak time and increasing the use of renewable energy sources. Smart grid provides advantages for electric companies and consumers that some of the most important ones are shown in Table 1.

In terms of economic status this system provides energy transfer with the most efficient and most economic method. Also in this network consumer can reduce his consumption by executing management flexible practices. Moreover by sending real time information about the status of consumption, the consumer can be encouraged to reduce carbon dioxide production and emission, and create a healthier environment for life.

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Table 1: Advantages of smart grid

Electric Company	Consumer
* Improve reliability	* Possibility of use of management practices
* Possibility of breakdown of costs in different parts of the network	* Advantage of new technologies in smart meters
* Reduce run costs and maintenance	* Saving cost with Reduction peak load
* Improve efficiency of power network	* Save money with increase efficiency
* Improve system security	* Improve services to customers in the electricity market
* Use of renewable energy and distributed generation resources in a centralized system	* Reduce the overall cost of industrial consumers

As fuel prices were sharply increased during recent years, Energy wastes costs more. So efficiency in electric generation, transmission and distribution is more critical. To enhance the efficiency, the following listed approaches are examined:

2.1 Distributed generation (DG) and Micro Grids

Noticeable waste of electricity happens in transmission and distribution level; by enabling DG in micro and island grids these amount of waste will be mitigated greatly.

2.2 DC power instead of AC power

A major part of today`s consumption of electricity is in residential and commercial regions. This energy is used in electronic devices, that consume DC power, so AC power should be converted to DC in such devices. In these conversions a large amount of losses occurs. On the other hand, by increasing renewable power plants and distributed sources, hybrid vehicles and battery storages another DC/AC conversion should be done in production side. Therefore, a considerable amount of losses which is up to 35% will be imposed on the system. On the other hand in this situation so many unnecessary convertors are included in the devices which cause increases in prices. Eliminating the need for multiple conversions could also potentially translate into lower maintenance requirements, longer-lived system components, and lower operating costs.

3 Effect of Smart Grid

Smart Grid is the collection of all technologies, concepts, topologies and approaches which allows the silo hierarchies of generation, transmission and distribution to be replaced with an end-to-end organically intelligent and fully integrated environment where business processes, objectives and needs of all stake holders are supported through efficient exchange of data, services and transactions. Smart Grid therefore is defined as a grid which accommodates a wide variety of generation options, e.g. central, distributed, intermittent and mobile. It empowers the consumers to interact with the energy management systems to manage their energy use and reduce their energy costs. Smart Grid is also a self-healing system. It predicts looming failures and takes corrective actions to avoid or mitigate system problems. Smart Grid uses information technology to continually optimize the use of its capital assets while minimizing operations and maintenance costs.

Mapping the above definitions to a practical architecture, one can readily see that Smart Grid cannot and should not be a replacement for the existing electricity grid, but a complement to it. In other words, Smart Grid would and should co-exist with the exiting electricity grid, adding to its capabilities, functionalities and capacities through an evolutionary path. This therefore necessitates a topology for the Smart Grid that allows for organic growth, inclusion of forward looking technologies and full backward compatibility with the existing legacy systems.

At the core, the Smart Grid is therefore an ad-hoc integration of complementary components, subsystems and functions under the pervasive control of a highly intelligent and distributed commanding and controlling system. Furthermore, organic growth and evolution of the Smart Grid is envisaged to be materialized through plug & play integration of certain basic structures which are called Intelligent (or Smart) Micro-grids. Micro-grids are defined as an interconnected network of distributed energy systems (loads & resources) that can function connected to or separate from the electricity grid. In Figure 1 Some of the key functions of this network are listed.

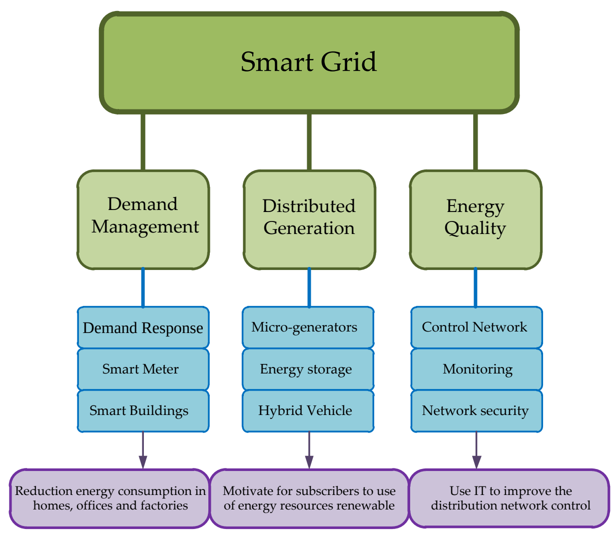

Fig. 1. Key Principles of smart grids.

4 Data Management

For the retail sales operation, the most important issue is the interface to the metering systems and to the substation control, or SCADA system. Some information may come from Customer Information System (CIS), some may come from GIS and some may come from SCADA. The engineer has to access several database systems to get the complete information. Second, the data in the original database may not be in the same form required by analytical tools. These interfaces produce the measurement based information, which mostly is necessary for load estimation and energy balance management. The expansion planning of the power system involves a wide range of tasks, as the following: determination of the number of locations and capacities of the future substations; and the planning of the number, routes and capacities of the feeders. The various computerized techniques available for distribution planning differ in approach, algorithm, data needs, and quality of results.

However, it requires base line information upon which the analysis can be performed.

The role of distribution and data management system and network automation system is to further increase the demand related information. The communication between these systems and the Distribution Energy Management (DEM) system will be arranged on an hourly basis. Integrating geographic and other corporate data to make maximum use of this valuable information has become of the primary interest for the power distribution utilities.

5 A Distribution Energy Management System

The problems of energy management from the standpoint of the energy trading and distributing companies in the new situation are first discussed. For distribution companies these mean big changes, since the network operation and energy selling activities will be separated. The customers have the right to choose between several power suppliers.

The main functions of the DEM system for Distribution Energy Management are:

1. Distribution load estimation
2. Load forecast, short, medium, and long term
3. Technical energy balance estimate
4. Commercial energy balance management
5. Load metering handling for billing
6. Selling/buying agreement management
7. Monitoring and control of distributed generation
8. Electricity purchase optimization
9. Pool price forecasting
10. Short term electricity trade optimization
11. Tariff design and retail sales planning
12. Load control optimization, direct and indirect
13. DSM planning functions
14. DSM impact verification
15. DSM impact models (pseudo-loads)

Estimation of load flows in the distribution system is based on the combination of models of type of users load, statistical data, customer information and measurements.

The model produces the best possible estimate of the state of the medium voltage distribution network up to the secondary (ML/LV) substations on a real time basis. Recently most researcher have adopted algorithm of Distribution State Estimation for distribution system [5]-[9].

The on line knowledge of loads is essential for the optimization of power generation and other electricity purchase. However in the free market, all the customers, which participate in the competition, are not necessarily metered real time. The hourly demands are obtained only afterwards, possibly with several weeks delay.

The hourly energy data must be known for calculation of the hourly trade between distribution utility and the energy supplier. Some of the customer loads are metered in real time, at every 15 minutes. Some of eligible customers have not the metering in real time; they have only the load estimates. Their hourly loads are obtained later on, until meter readings will be available. However, on line (one hour ahead) forecasts of loads in the distribution system are needed for the trader's estimate of power generation and electricity purchase.

The problem of delayed load data can be solved by the on line estimation of customers' loads. The estimation is based on the past recordings of hourly demands, customer class load models and if available, on line measurements in the distribution network. On line measurements can be planned for the loads of medium voltage distribution feeders.

By combing the measurement data with load models, an estimate can be produced for the hourly demands of the customers.

More severe concerned problem is the uncertainly in the announced estimates of the loads of other traders' customers in the area of selling company.

By combining network data and customer data load models for customer's classes was acquired. When linear model is used the resulting load value depends on annual energy consumption of the class, parameter obtained from the load model and the error.

$$W_{sl} = W_{11} + \ldots + W_{ml}, \ldots, W_{sn} = W_{1n} + \ldots + W_{mn} \tag{1}$$

And estimates from load models

$$z_1 + v_1 = W_{sl} x_1, \ldots z_n + v_n = W_{sn} x_n \tag{2}$$

We use matrix representation for the customers class loads z1…zn .

$$\begin{bmatrix} z_1 + v_1 \\ \vdots \\ z_n + v_n \end{bmatrix} = \begin{bmatrix} W_1 & \cdots 0 & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots 0 & W_n \end{bmatrix} . \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \Leftrightarrow z + v = W_z . x \tag{3}$$

For the measurement we get the following equations where e represents measurement.

$$\left\{ \begin{matrix} S_1 + e_1 = W_{11}.x_1 + W_{11}.x_1 + W_{12}.x_2 + \cdots + W_{1n}.x_n \\ \vdots \\ S_m + e_m = W_{m1}.x_1 + W_{m2}.x_2 + \cdots + W_{mn}.x_n \end{matrix} \right\} \tag{4}$$

and the matrix representation

$$\begin{bmatrix} S_1+e_1 \\ \vdots \\ S_m+e_m \end{bmatrix} = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{12} & W_{22} & \cdots & W_{2n} \\ \vdots & & \ddots & \\ W_{m1} & W_{m2} & \cdots & W_{mn} \end{bmatrix} . \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \Leftrightarrow S+e=W_s.x \qquad (5)$$

The measurement error variance must be estimated from the reliability of the measurements. When we have measurements of the current, the transformation of current to active power includes error, which may be estimated to have a standard deviation of 10% from the absolute value of measurement. Thus the direct measurement has a smaller error variance than the load models. This means the smaller the error variance the higher the weight and then larger the variance the smaller the weight. The models will change to fit the values of measurements in relation to their model variances. The point estimates of values with high variance are more likely to change than values with low variance.

The general solution of the WLSE (Weighted Least Squares Estimation) [10] operation problem z = Ax is

$$\min\left[(c - A.b)^T.R^{-1}.(c - A.b)\right] \qquad (6)$$

$$\hat{x} = \left[\begin{bmatrix} W_z \\ W_s \end{bmatrix}^T R^{-1} \begin{bmatrix} W_z \\ W_s \end{bmatrix}\right]^{-1} \begin{bmatrix} W_z \\ W_s \end{bmatrix}^T R^{-1} \begin{bmatrix} z \\ S \end{bmatrix} \qquad (7)$$

Where

$$R^{-1} = \begin{bmatrix} 1/\sigma_1^2 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 1/\sigma_n^2 & 0 & \cdots & 0 \\ 0 & \cdots & 0 & 1/\sigma_{s1}^2 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 & \cdots & 1/\sigma_{sm}^2 \end{bmatrix} \qquad (8)$$

With help of this result we can solve the new estimates for z customer classes and S for feeder loads:

$$\hat{z} = W_z x' \qquad (9)$$

$$\hat{s} = W_s x' \qquad (10)$$

These values are now the best estimates for customer class loads and feeder measurements in the WLS sense.

6 Simulation Results

In order to assess the role of the smart grid in the estimation of time and energy management, 33 feeder radial distribution network which is shown in Figure 2 has been used. The number of consumers is assumed as 384 joint, and in every feeder there are 12 consumers.

Consumers are divided into five main types:

1. Domestic consumers (DC)
2. Small commercial consumers (SC)
3. Medium commercial consumers (MC)
4. Large commercial consumers (LC)
5. Industrial consumers (IC)

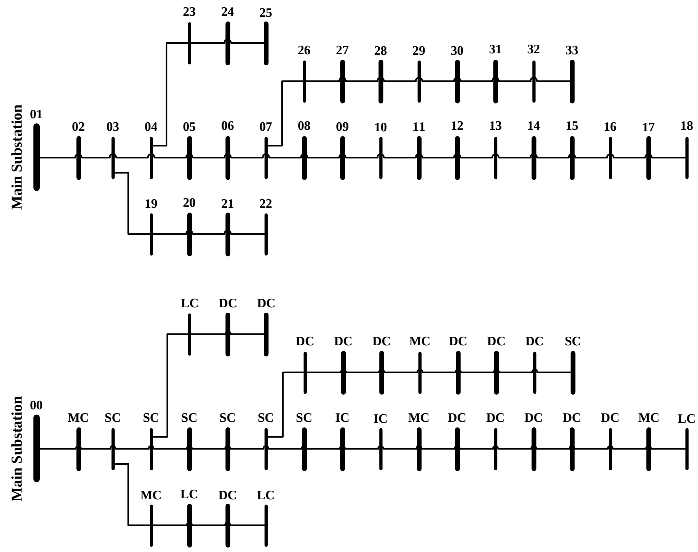

Fig. 2. distributed network studied (33 Feeder IEEE) .

Respectively values -0.15, -0.14, -0.23, -0.30, -0.40 for the elasticity consumer price and the amount of energy tariffs 0.21, 0.23, 0.24, 0.19, 0.14 of $/kWh for consumers DC ، SC ، MC ، LC ، IC is intended. Interest rate of consumers against the amount of energy primary tariffs for each consumer is assumed.

Consumer information, including their type and amount of energy are listed in Table 2. As was pointed out constraints such as maximum allowable reduction of power and maximum allowable change in energy prices for consumers is considered. In this paper, the maximum allowable power consumption equal to 15% reduction in energy consumption of each consumer and maximum allowable change in the price of energy equal to 30% of energy tariffs is considered.

Table 2: Information of consumers

Type of consumer	Power	Feeder
MC	100	1
SC	90	2
SC	90	3
SC	90	4
SC	90	5
SC	90	6
SC	90	7
IC	420	8
IC	420	9
MC	120	10
DC	60	11
DC	60	12
DC	60	13
DC	60	14
DC	60	15
MC	120	16
LC	200	17

MC	150	18
LC	210	19
DC	60	20
LC	200	21
LC	200	22
DC	60	23
DC	60	24
DC	45	25
DC	60	26
DC	60	27
MC	120	28
DC	60	29
DC	60	30
DC	60	31
SC	90	32
…	3715	Total

Figure (3) shows the reduced energy consumption for each mode in each type. As it is shown in Figure (3) with increasing consumer participation in smart grid energy reduction will be increased.

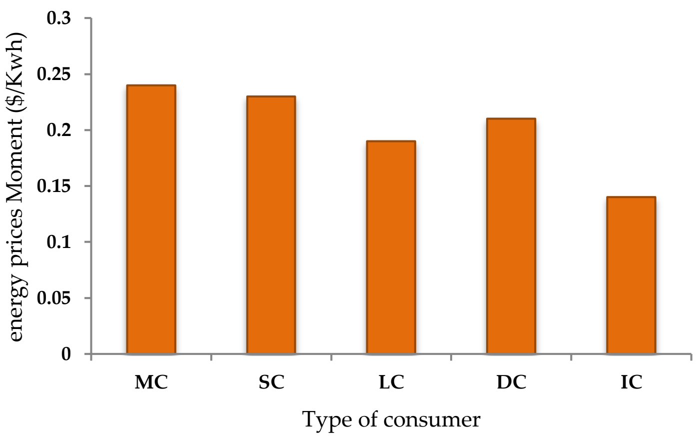

Fig. 3. Energy prices moment for consumers.

Lack of expected reduction for MC type users is due to their higher interest in purchasing price of the electricity energy market.

It is noteworthy, Instantaneous change in consumer prices is more for SC and DC consumers than consumer type of LC and IC;this change is more due to lower capacity of demand prices and the higher initial tariffs for energy for this type of the consumers.

Energy purchase cost of the electricity market, the amount of system losses and the lowest voltage distribution network are shown in Table 3.

Figure 4; also show the reduction of energy consumption in each mode for each type.

Table 3: Impact of smart grid on energy purchase costs, Losses and voltage distribution network

	traditional network	Smart Grid
Energy purchase costs of the electricity market ($)	934.2	857.4
losses Distribution network (Kwh)	187.5	162.2
Low voltage distribution network (pu.)	0.9659	0.9721

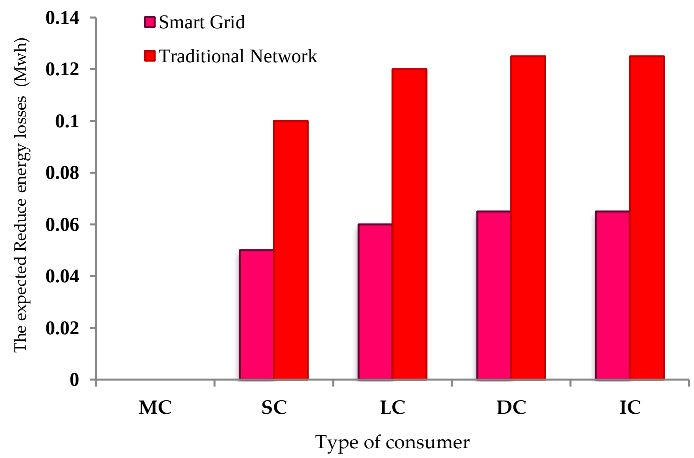

Fig. 4. Rate the expected reduce energy losses.

As is specified with increasing consumer participation in the smart networks, energy purchase costs and distribution losses has been reduced considerably and the system voltage profile is improved.

In a case that the network load increases 30%, In addition to the problem of voltage drop in the network the rate of transmission of power reaches its maximum, the operator is forced to cut more load in the network. But similar to the previous mode and While the energy purchase price is lower than the amount of consumer interest, the smart grids with the optimum price spot for the Types of Consumers, can be exploited in the distribution network in authorized area without Forced outages load.

The results for this mode in the smart grids and conventional networks are specified in Table (4).

Table 4: The effect of smart grid in increasing the network load

	20% increased load		30% increased load	
	traditional network	Smart Grid	traditional network	Smart Grid
Energy purchases from electricity market (Kwh)	4691.8	4540.2	4922.3	4744.1
losses Distribution network (Kwh)	255.9	242.3	268.4	260.7
Stop load (Kw)	31.2	-	281.2	-

7 Conclusion

In the deregulated electricity market, the power trading companies have to face new problems. The biggest challenge is caused by the uncertainty in the load magnitudes. In order to minimize the risk in power purchase and also in retail sales, the power traders should have the most possible reliability and accuracy in estimates for hourly demands of their customers. New tools have been developed for the distribution load estimation of the trading companies.

These tools are based on the flexible combination of the information available from several sources, like load measurements, load models, statistical data in combination with Smart Grid.

The combination of Smart Grid and Distribution Load Estimation algorithm could be used in conjunction with other operational tools such as:

1. Utilization of Demand Side Management (DSM) to control loads in order to reduce the peak power demand or peak price
2. Accordingly can be used recursively for a better dynamic load models for HV/MV substations
3. Planning of tariff offers and methods to modify the customer load curve
4. Better utilization of the distribution MV lines and transformers ML/LV
5. Saving in network investments
6. Reduction in outage costs
7. Integration of the distribution utility's and customer's automation system for load control
8. Better competitiveness in the electricity market.

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