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A Novel Apporoach To Dependent Demand Response Management In The Smart Grid

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Abstract: *Now-a-days technology has developed to a large extend. At the same time the need for systems with automation and high security are preferred. To overcome new challenges, such as generation diversification, greenhouse gas emissions regulation, energy conservation, demand response and a new liberalized market system. It is clear that these cannot be resolved with the current infrastructure. Global energy generation and delivery systems are transitioning to a new computerized "smart grid". One of the principle components of the smart grid is an advanced metering infrastructure (AMI). AMI replaces the analog meters with computerized systems that report usage over digital communication interfaces, e.g., phone lines. However, with this infrastructure comes new risk. Smart grid is the integration of advanced information, communication and networking technologies in traditional electric grid to make it smarter and faster in making decisions. The new proposed electric grid is helpful for providing uninterrupted power supply to the loads with automated demand management. The demand management was proposed with demand response management by shifting the loads to the weak bus once if the bus is loaded with its maximum capacity. To improve the performance of the power system, smart grid technology is implemented with automated metering interface that provides two way communications between the utility and supply.*

Keywords: *consumer welfare, demand response management (DRM), cost efficiency, renewable energy, smart grid, voltage frequency controller, Automated Metering Interface (AMI).*

THE GROWING DEMAND of electricity, the aging infrastructure, and the increasing greenhouse gas emission are some of the challenges with the traditional power grid. Recent blackouts [1] have further corroborated these issues, grid into a more responsive, efficient, and reliable system. The smart grid [2], widely believed to be the future power grid, offers improved efficiency, reliability, and environmental friendliness in power generation, transmission, distribution, consumption, and management, by integration of advanced information and communication technologies. Demand response management (DRM) is the response system of end users to changes in electricity prices over time or to other forms of incentives. In the smart grid, DRM plays a key role in improving different aspects of both supply and demand sides. For instance, DRM can result in lower bills and higher utility efficiency for end users. DRM can also reduce the cost of power generation or improve the revenues to retailers or utility companies (UCs). In DSM, the pricing mechanisms and direct control strategies are employed by the energy suppliers to affect consumers' consumption behaviors and reshape the total load [3]–[5]. The time-of-use pricing strategy sets different prices during the day to encourage consumers to shift their demand to off-peak hours [7]–[9]. Similar to the time-of-use pricing, the critical peak pricing applies a pre specified high price during the designated critical peak periods [10], [11]. Along with the DSM techniques, the integration of distributed energy resources (DERs) into the grid can also effectively increase the grid's capacity and reduce the emission of $CO2$ [12], [13]. Equipped with the distributed energy generation, the residential customers can also participate in the electricity market as an energy supplier. In this system we make use of two algorithms the demand response management algorithm along with v/f controls.

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I. Related Work

Several studies on demand side management and DRM have focused on either only one utility or a number of utilities treated as one entity [5]–[10]. Mohsenian-Rad *et al.* [3] have formulated an energy consumption scheduling problem as a non-cooperative game among the consumers for increasing and strictly convex cost functions. Fan [7] has considered a distributed system where price is modeled by its dependence on the overall system load. Based on the price information, the users adapt their demands to maximize their own utility. In [9], a robust optimization problem has been formulated to maximize the utility of a user, taking into account price uncertainties at each hour. Wang and Groot [8] have exploited the awareness of the users and proposed a method to aggregate and manage end users' preferences to maximize energy efficiency and user satisfaction. In [9], a dynamic pricing scheme has been proposed to provide incentives for customers to achieve an aggregate load profile suitable for UCs, and the demand response problem has been investigated for different levels of information sharing among the consumers. In [10], a multi resolution two-layer game is studied using mean-field game approach to incorporate inner interactions between users in the region and outer interactions between regions for dynamic distributed demand response in the smart grid. References [11] and [12] have also incorporated electric vehicles into the DRM framework. To this end, compared to relating existing literature we propose a system which can change the source when there is an increase in the threshold load, where here the measurement of load is obtained using the 1. DRM (demand response management system) and the shifting is done by using the 2.v/f controller.

II. System Model

Fig. 1 depicts our hierarchical system model, which consists of three levels: 1) power generation units at the top level; 2) distribution algorithms and 3) residential and industrial consumers at lowest bottom with AMI (Automated Metering Interface). The framework is motivated by the hierarchy of the real power grid system. The power generation units or power plants supply power, the UCs determine the unit price and optimal amount of power to supply, and the bottom level represents the demand response to the price signal from the residential consumers. The power generation units, UCs and the consumers have bidirectional communications support to exchange price and demand information. The data communication is carried out through the communication channel using wireless technologies.

III. Demand Side Analysis

Let *y* be the price per unit power. For given *y*, user *n* ($n \in NR$) calculates its optimal demand response by solving the user optimization problem to maximize its welfare $W_{R,n}$ as follows:

$$\max_{\mathbf{x}_{R,n}} \quad W_{R,n} := U_{R,n}(x_{R,n}) - y x_{R,n} \qquad (1)$$

$$\text{s.t.} \quad x_{R,n} \geq x_{R,n,\min} \qquad (2)$$

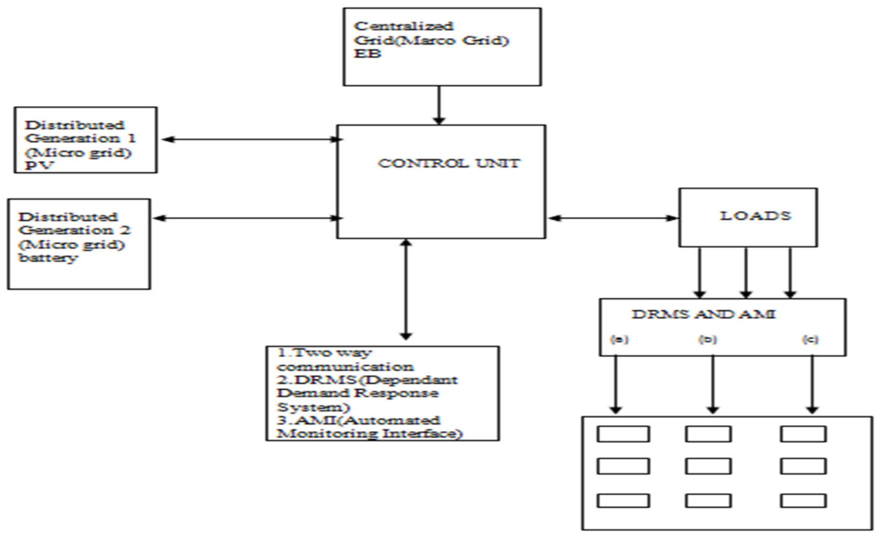

FIG.1 System model of smart grid system

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where $xR,n,\min$ is the minimum power requirement of consumer n. The above, that is, (1) and (2) characterizes a strictly convex optimization problem for given y. Hence, the stationary solution is unique and optimal. The first-order optimality condition for the optimizing residential user leads to $(\partial WR,n/\partial xR,n,k) = 0, \forall n \in NR$, that is

$$U'_{R,n} = y, \Rightarrow x_{R,n} = \left(U'_{R,n}\right)^{-1}(y). \qquad (3)$$

The condition required for constraint (2) to be satisfied can be established by substituting (3) into (2), which requires $y \le [U\_\ R,\ n]\ xR,\ n = xR,\ n,\ \min, \forall n \in NR$. This can be ensured if

$$y \le y_{\max} := \left[U'_{R,n}\right]_{\substack{\min\\ n\in\mathcal{N}_R}\ x_{R,n}=x_{R,n,\min}}. \qquad (4)$$

For the purpose of illustration and to provide function specific insights, we employ two widely adopted gain functions for residential consumers: 1) piecewise quadratic function [12]; and 2) logarithmic function [10]. We define the piecewise quadratic gain function of residential user n, $(n \in NR)$, as

$$U_{R,n}\left(x_{R,n}\right) = \begin{cases} v_{R,n}x_{R,n} - \dfrac{z_{R,n}x_{R,n}^2}{2}, & \text{if } x_{R,n} \le \dfrac{v_{R,n}}{z_{R,n}} \\ \dfrac{z_{R,n}}{2v_{R,n}} & \text{if } x_{R,n} > \dfrac{v_{R,n}}{z_{R,n}} \end{cases} \qquad (5)$$

where vR,n and zR,n are user-specific parameters $\forall n \in NR$. In this case, (3) and (4), respectively, take the form

$$x_{R,n} = \frac{\left(v_{R,n} - y\right)}{z_{R,n}} \qquad (6)$$

And

$$y \le y_{\max} := \min_{n\in\mathcal{N}_R}\left(v_{R,n} - z_{R,n}x_{R,n,\min}\right). \qquad (7)$$

The logarithmic gain function can be defined for residential user n, $(n \in NR)$, as

$$U_{R,n}\left(x_{R,n}\right) = \alpha_{R,n}\ln\left(\beta_{R,n} + x_{R,n}\right), \quad \forall k \in \mathscr{K} \qquad (8)$$

where $\alpha R,n$ and $\beta R,n$ are user-specific parameters. In this case, for given y, (3) and (4), respectively, take the form

$$x_{R,n} = \frac{\alpha_{R,n}}{y} - \beta_{R,n} \qquad (9)$$

And

$$y \le y_{\max} := \min_{n\in\mathcal{N}_R}\frac{\alpha_{R,n}}{\beta_{R,n} + x_{R,n,\min}}. \qquad (10)$$

IV. Supply Side Analysis

If the total power supplied by UC k is Pk, the profit of provider k is defined as

$$R_{\mathrm{UC},k} = yP_k - C(P_k). \qquad (11)$$

Then, the optimization problem for each UC is as follows:

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$$\begin{aligned} \max_{0\le y\le y_{\max}, P_k\in\mathbb{R}_+} \quad & R_{\mathrm{UC},k} \\ \text{s.t.} \quad & P_I + \sum_{n\in\mathcal{N}_R} x_{R,n} \le \sum_{k\in\mathcal{K}} P_k \\ & P_k \le P_{k,\max};\ \forall k\in\mathcal{K} \qquad (12) \end{aligned}$$

where Pk,max is the maximum power UC k can supply. When Pk,max is sufficiently large, PI , $Pk << Pk,\mathrm{max}$. Then the second constraint can be relaxed. For a given y, (12) is a convex optimization problem. Given y, the first-order optimality condition for the UCs, $(\partial R\mathrm{UC},k/\partial Pk) = 0$, gives the optimal amount of power to be supplied by UC k as

$$P_k = \left(C'_k\right)^{-1}(y);\ \ \forall k\in\mathcal{K}. \qquad (13)$$

Normally, if the power supplies of different UCs are given, the unit prices would be calculated based on the given power supplies. However, we are considering here a planning level problem where both unit price and optimal power to be supplied, are the variables. Thus, the optimal power of each UC is calculated by backward induction, based on the optimal unit price, a parameter obtained as a result of the profit optimization of the UCs. With the optimal demand response of residential users (3) and UCs' power supply (13) in response to the price y, the objective of the UCs is to set the optimal price y. For supply demand equilibrium, it is required that

$$\sum_{k\in\mathcal{K}} P_k = P_I + \sum_{n\in\mathcal{N}_R} x_{R,n}. \qquad (14)$$

Substituting (3) and (13) into (14) we obtain

$$\sum_{k\in\mathcal{K}} \left(C'_k\right)^{-1}(y) = P_I + \sum_{n\in\mathcal{N}_R} \left(U'_{R,n}\right)^{-1}(y). \qquad (15)$$

where $G1(y) = \_k\in K\ (C\_k)\ -1(y) - \_n\in NR\ (U\_R,n)-1(y)$. We employ a quadratic cost function for power generation [12], [13]. Let $ak > 0$ and $bk,\ ck \ge 0$ be the coefficients of the cost function $Ck(Pk)$. Then, if the total power supplied by UC k is Pk, then the cost incurred to the UC is

$$y = (G_1)^{-1}(P_I) \qquad (16)$$

When the gain functions of the residential consumers are piecewise quadratic as given by (5), (16) takes the form

$$C_k(P_k) = a_k P_k^2 + b_k P_k + c_k. \qquad (17)$$

Proposition 1: When the gain functions of the residential consumers are piecewise quadratic as given by (5), (18) is the unique feasible solution to the profit maximization problem (12) only if

$$y = \frac{P_I + \sum_{k\in\mathcal{K}} \frac{b_k}{2a_k} + \sum_{n\in\mathcal{N}_R} \frac{v_{R,n}}{z_{R,n}}}{\sum_{k\in\mathcal{K}} \frac{1}{2a_k} + \sum_{n\in\mathcal{N}_R} \frac{1}{z_{R,n}}}. \qquad (18)$$

Proof: Since $ak > 0,\ bk,\ ck \ge 0,\ \forall k \in K$, $vR,n,\ zR,n > 0,\backslash\ \forall n \in NR$, and $PI \ge 0$, (18), implies that $y > 0$. For given $ak,\ bk,\ ck\ \forall k \in K$, and $vR,n,\ zR,n\ \forall n \in NR$, substituting (18) into (7), we obtain

$$\begin{aligned} P_I \le P_{I,\max} \coloneqq & \left(\min_{n\in\mathcal{N}_R}\left(v_{R,n} - z_{R,n}x_{R,n,\min}\right)\right) \\ & \times \left(\sum_{k\in\mathcal{K}} \frac{1}{2a_k} + \sum_{n\in\mathcal{N}_R} \frac{1}{\alpha_{R,n}}\right) \\ & - \left(\sum_{k\in\mathcal{K}} \frac{b_k}{2a_k} + \sum_{n\in\mathcal{N}_R} \frac{v_{R,n}}{\alpha_{R,n}}\right). \qquad (19) \end{aligned}$$

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$$\frac{P_I + \sum_{k\in\mathscr{K}} \frac{b_k}{2a_k} + \sum_{n\in\mathscr{N}_R} \frac{v_{R,n}}{z_{R,n}}}{\sum_{k\in\mathscr{K}} \frac{1}{2a_k} + \sum_{n\in\mathscr{N}_R} \frac{1}{z_{R,n}}} \leq \min_{n\in\mathscr{N}_R} \left(v_{R,n} - z_{R,n}x_{R,n,\min}\right).$$

Further simplification of (20) yields (19). *Remark 1:* Note that, UCs may impose their own limits on the unit price, and usually there is a maximum limit the market imposes, i.e., $yk,\min \leq y \leq ym,\max$ $\forall k \in K$. Without loss of generality, we consider $y\max \leq ym,\max$ and $y \geq yk,\min$ $\forall k \in K$. *Proposition 2:* When the gain functions of the residential consumers are logarithmic as given by (8), a unique feasible solution of (12) is

$$y = \frac{-T_1 + \sqrt{{T_1}^2 + 8AA_R}}{2A}, \text{ if} \tag{21}$$

$$P_I \leq \min_{n\in\mathscr{N}_R} \frac{A\alpha_{R,n}}{2(\beta_{R,n} + x_{R,n,\min})} - \frac{B_A}{2} + B_R - \frac{A_R}{\min\limits_{n\in\mathscr{N}_R} \frac{\alpha_{R,n}}{\beta_{R,n}+x_{R,n,\min}}} \tag{22}$$

where $T1 = 2BR - BA - 2PI$, $A = \_k\in K\ 1/ak$, $AR = \_n\in NR\ \alpha R,n$, $BR = \_n\in NR\ \beta R,n$, and $BA = \_k\in K\ bk/ak$. *Proof:* Substituting Ck, UR,n from (17) and (8) into (15) and further simplification yields

$$\sum_{k\in\mathscr{K}} \frac{y - b_k}{2a_k} = P_I + \sum_{n\in\mathscr{N}_R} \left(\frac{\alpha_{R,n}}{y} - \beta_{R,n}\right). \tag{23}$$

The solution of (23) is $y = (-T1$ □} $\_T12 + 8AAR/2A)$.Since $A > 0$ and $\_T12 + 8AAR > T1$, the root $y =(-T1 + \_T12 + 8AAR/2A)$ is the only real, positive one, and hence, feasible solution for y. Now, substituting (21) into (10) leads to

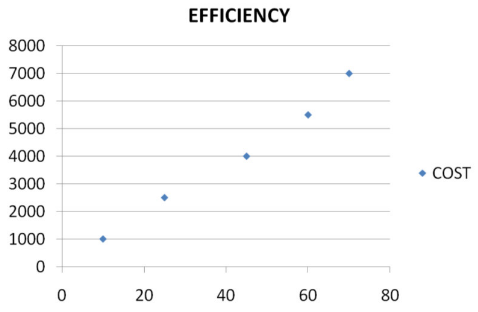
$$\frac{-T_1 + \sqrt{{T_1}^2 + 8AA_R}}{2A} \leq \min_{n\in\mathscr{N}_R} \left(\frac{\alpha_{R,n}}{\beta_{R,n} + x_{R,n,\min}}\right). \tag{24}$$

Squaring both sides of (25) and upon further simplification, (25) takes the form (22).

$$2A\left(\min_{n\in\mathscr{N}_R} \frac{\alpha_{R,n}}{\beta_{R,n} + x_{R,n,\min}}\right) + T_1 \geq \sqrt{{T_1}^2 + 8AA_R}. \tag{25}$$

Remark 2: If for any of the UCs, $(C\_ k) -1(y) > Pk,\max$, then instead of using (13), UC k supplies $Pk = Pk,\max$. The power supply from UC k can, therefore, be expressed as $Pk = \min((C\_ k) -1(y), Pk,\max)$

V. Performance Measures of Our Proposed System



VI. Conclusion

We have proposed a system which is incorporated with dynamic demand side management with the use of smart grid using the three major systems the demand response management, v/f controller and the AMI(Automated Metered Reading) which plays a major role to send the information about power usage and storage details (i.e.,) the battery backup. With our system we can give uninterrupted

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supply to our customers even in the case of sudden surge in the load by shifting the phase automatically and again details regarding the usage is obtained via AMI.

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