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A Reliability-Cost–Benefits (RCB) Model for the Addition of DG to Independent Micro-Grid Networks

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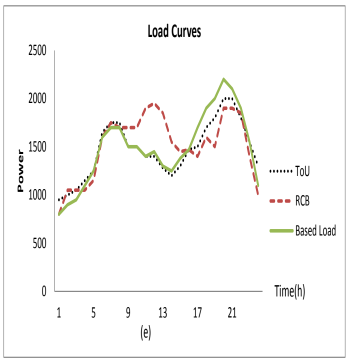
Graphical abstract



Abstract

Interest in alternative energy sources has been increased due to improved public awareness about the high energy cost and the adverse environmental impact of the conventional energy sources. This has caused a transition to a new market-based power network which, among other characteristics, allows more flexible incentives based demand-response-programs (DRP). Reliability aspects have been more challenging in remotely operated Independent-Microgrid-Networks (IMGN) mainly due to weather dependence. Such stochastic behavior has influenced the market prices of electricity and has created real time challenges for trade. The success of such uncertain energy systems depends to a large extent on new technical and financial tools. This requires to consider together the reliability and the financial cost–benefit analysis for every stakeholder of the deregulated electricity market. A novel decision making strategy for relating the system's reliability with cost-benefit incentives under IMGN paradigm has been proposed with an application of economic and signaling-game-theory (SGT).A relationship has been formulated with the consideration of maximizing the profit expectation of each player in the presence of the independent multi-generation resources with different penetration levels. This proposed model can be used as a tool for task scheduling problems and demand side management under the real time pricing schemes. The basic idea is to deal with the uncertainties involved to improve the reliability of renewable power systems. A simulation methodology for reliability evaluation and cost assessment in IMGN has also been developed. Results are discussed in comparison with the Time-of-Use (ToU) price rates.

Keywords: Demand response; micro grid; renewable; reliability; economic

Abstrak

Kepentingan dalam sumber tenaga alternatif telah berkembang dengan adanya peningkatan kesedaran orang awam tentang kos tenaga yang tinggi dan kesan alam sekitar yang buruk dengan menggunakan sumber tenaga konvensional. Ini telah menyebabkan berlaku peralihan kepada rangkaian kuasa baru berasaskan pasaran di mana, di antara ciri-ciri lain, ia menggalakkan insentif yang lebih fleksibel berdasarkan program permintaan–tindak balas (DRP). Aspek kebolehupayaan menjadi lebih mencabar dalam operasi kawalan jauh rangkaian jenis Independent-Microgrid-Networks (IMGN) terutamanya disebabkan oleh kebergantungan keadaan cuaca. Beberapa tingkah laku stokastik telah mempengaruhi harga pasaran elektrik dan telah mewujudkan cabaran masa sebenar dalam perniagaan. Kebolehan sesuatu sistem tenaga kebanyakannya bergantung kepada perkembangan alat teknikal dan kewangan yang baru. Ini diperlukan untuk mempertimbangkan bersama tentang kebolehupayaan dan analisis kewangan jenis kos–faedah bagi setiap pihak berkepentingan yang berada dalam pasaran elektrik dikawal selia. Sejenis strategi terkini dalam membuat keputusan untuk menghubungkan kebolehupayaan sistem dengan insentif jenis kos–faedah di bawah paradigma IMGN paradigma telah dicadangkan dengan penggunaan ekonomi dan teori jenis isyarat –permainan (SGT). Satu hubungan telah dirangka dengan mengambil kira jangkaan keuntungan maksimum daripada setiap pemain dalam kehadiran sumber pelbagai generasi bebas dengan kaedah yang berbeza. Model yang dicadangkan ini boleh digunakan sebagai alat untuk masalah penjadualan tugas dan pengurusan dari segi permintaan di bawah skim harga masa nyata. Idea asas adalah untuk menyelesaikan ketidakpastian yang wujud bagi meningkatkan kebolehupayaan sistem kuasa yang diperbaharui. Satu kaedah simulasi untuk penilaian kebolehupayaan dan penilaian kos di IMGN juga telah dibina. Hasil dapatan dibincangkan dalam perbandingan dengan kadar harga penggunaan–masa (ToU).

Kata kunci: Tindak balas permintaan; grid mikro; diperbaharui; keboleupayaan; ekonomi

■1.0 INTRODUCTION

Smart Grid (SG) is evolving changes in the paradigm of the electricity market's organization and management with two-way modern communication and control technologies. The emerging vision of the SG encompasses a broad range of applications including hardware and software technologies[1]. This helps the utilities to identify and fix the imbalances between supply and demand instantaneously and improves the service quality by detecting faults in a 'self-healing' process. This enables an efficient management of consumer's electricity usage via different types of Demand-Side-Management (DSM) / Demand-Response (DR) choices. Consumers are provided with attractive financial incentives and benefits[2-4] to motivate them to participate in the operations of the grid. The usage of renewable energy resources has gained significant popularity in recent times. The reasons include economic and environmental concerns about the conventional electrical energy resources. Renewables are usually considered environment friendly but not all of them are reliable, efficient and cost effective[5,6]. Limitations regarding the available generated energy and uncertain load behavior are the key factors influencing the reliability of an IMGN. The assurance of maintaining the system balance all the time is expected to pose a big challenge while bidding in electricity market[7-9].

Market implementation of various DRPs approaches is expected to lead improvements in power system efficiency and price reduction by ending monopolies[10]. However, the experiences show that problems have occurred while relating the very specific characteristics of IMGN with market trading. In this context, grid operators and utilities are taking new initiatives by recognizing the value of DR for grid reliability and for the enhancement of organized spot market's efficiency. Reliability varies significantly all the time due to IMGN resource heterogeneity and different administration strategies. This variable reliability causes a considerable impact on electricity prices, influences the trading market in IMGN, and poses a real time challenge for the electricity market. A review of the aggregate offers made by consumers shows that even a modest increase in demand elasticity could dramatically reduce the extremes in price volatility[14]. However, consumers have neither the expertise nor the motivation (due to the associated discomfort) to negotiate themselves in the market. In order to address these challenges, a strong need exists to increase the customers' participation in markets. This can be achieved by providing attractive financial benefits and simplifying the market process to enhance the system reliability and reduce price volatility[15,16]. In future, the customers will own distributed energy production facilities that can be "aggregated" and operated intelligently in the electricity market. The optimal utilization of local resources with the consideration of achieving maximum benefits for each player may prove a promising element for the success of IMGN stakeholder interactions. In this respect, it seems vital to assess the relation between reliability and compensation benefits of market players under IMGN paradigm. These need to be related together to provide a tool that can be utilized by consumers to enjoy appropriate financial incentives for participation in the market, and to facilitate the network operator for a successful operation of the system[17,18].

Different market based approaches for DRPs are under consideration by various ongoing academic research and thus far have been based on producer centric ideas[20]. The offered solutions intend to the collections of consumer information and their processing for the purpose of market regulation and planning. Linear economic DR models are developed and used in[21,22] with the assumption of linear demand changes and constant elasticity. Another research in article[18] had proposed an agent-based bidding technique for energy cost optimization that depends on interaction between demand and supply market. Attention has been focused on performing optimization on consumer-side through time shifting task preferences without hard deadline guarantees. However, these researches did not involve the issues of how to distinguish the grid reliability with the consideration of stochastic behavior of demand/generation in the market mechanism and relate it to the cost- benefit of stakeholders under IMGN paradigm[24,25].The core contribution of this paper is to present a novel decision making strategy for relating the system reliability with cost-benefit incentives under independent MGN paradigm with the application of economic and SGT.A relationship is formulated with the consideration of maximizing the profit expectation of each player in the presence of the independent multi-generation resources with different penetration levels. This method offers dual-purpose and can be used as a decision making tool for both IMGN operator and customers in energy management schemes. The performance and potential of the proposed approach is successfully validated with numerical simulations with decrease computation time.

■2.0 PAPER ORGANIZATION

The rest of this paper is organized as follows: Section 3 provides the formulation of IMGN market problem and model statement. The proposed RCB Model formulation is explained in detail in the same Section. The procedure of implementation framework and simulation strategy is described in Section 4. Concluding remarks are given in Section 5.

■3.0 IMGN ELECTRICITY MARKET-ORIENTED STRUCTURE AND MODEL FORMULATION

In this paper, an agent-based market oriented scheme is envisaged on an IMGN. The cooperation among the different stakeholders of the market is based upon bidirectional information exchange and their ability to access and correlate this information. An IMGN must be operated according to their participant's benefit and also try to achieve equilibrium between the generation and demand at higher energy efficiency with significant integration of local DG.

3.1 Imgn's Agents

An agent is defined as the entity (software or hardware wise) situated in a certain environment with the capability of independent action on behalf of its owner or user[26,27]. Here, two types of agents are defined for the proposed model.

3.1.1 Demand Agents

Demand Agent (DA) is defined here as one of the key stakeholders of electricity. Agents in this domain enable customers to manage their generation and energy usage. This involvement could be based on incentive motivation or other personal interest by showing willingness to adjust its energy behavior depending upon issued dynamic price signals[17,19,20].

3.1.2 Resouce Agents

IMGN operator is responsible for providing the infrastructure management and distribution of electricity to DA. They can also gather information for the estimation of the future energy demand on the grid and compare it against the available reserve capacities. This leads to better planning, management and utilization[27].

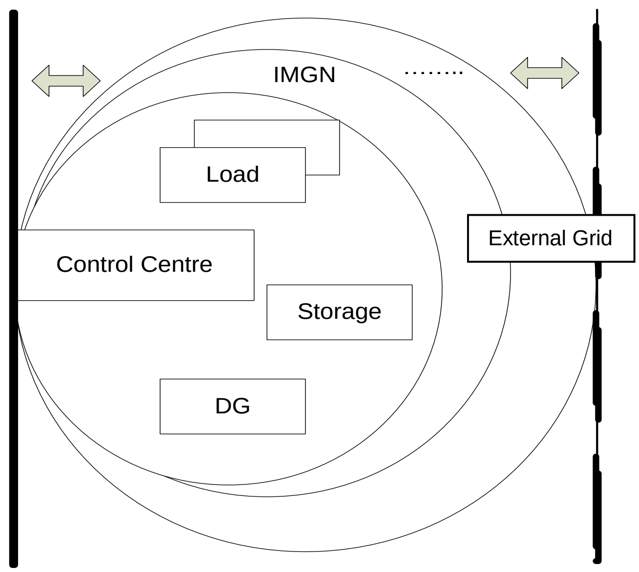


Figure 1 A layout of IMGN

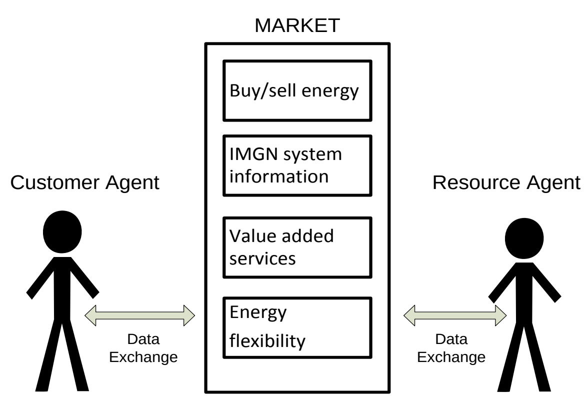


Figure 2 Market oriented structure of IMGN

3.2 Reliability Based Cost-Benefit Model For Imgn

This work introduces the application of SGT and economic theory on the estimation of the financial Cost-Benefit (CB) price based on the grid reliability.

3.3 Problem Statement

Reliability related issues have been increased with higher penetration of renewable energy resources. Uncertainties of the system load and with limited control on variable generation are intensifying this problem and causing a considerable impact on the electricity market. With the application of SGT, we can consider the IMGN reliability as the RA type endowed by nature. The CB price based on reliability is evaluated and sent it to DA via signals. Then DA deduces required information from this information. Profit maximization is considered as the global goal for both players. Here, IMGN reliability is defined as the probability of non-failure during the market trade.

3.4 Model Formulation

Suppose r_t is the reliability of the IMGN at time t.It varies with variable generation from DG and load demand, where $0 < r_t < 1$ and $r'_t = 1 - r_t$.

$P_t^{CB}$is defined as cost-benefit price given to the customer at hour "t" for each kWh load reduction. Based on the existing value of grid reliability, RA estimates the corresponding electricity price P_t^R along with the Cost-Benefit price P_t^{CB} and submits these values as selling bids to the market operator. DA manipulates these information and submits estimated buying bids to the market operator. In turn, the market operator clear the market using an appropriate market clearing procedure that results in energy prices and accepted selling and buying bids. It is assumed that during trading, DA will gain an amount of profit β, otherwise will lose an amount γ .where $\beta > P_t^R > 0$, $\gamma > P_t^{CB} \geq 0$ by the rationality.

Since DA determines Bargain probability (μ_t) after observing the signal of Cost-Benefit price (P_t^{CB}) Therefore Bargain probability (μ_t) is considered as the function of P_t^{CB}i.e $\mu_t = f(P_t^{CB})$

$$f(P_t^{CB}) = a\frac{P_t^{CB}}{P_t^R} + b \quad (1)$$

Where a and b are co-efficient with the restriction: a >0, 0 ≤b≤1

The profit function of both RA and DA is the function of reliability, Cost-Benefit price and Bargain probability. Therefore, is represented by $U_t^r\,(r'_t, P_t^{CB}, \mu_t)$ and $U_t^D\,(r'_t, P_t^{CB}, \mu_t)$.

The RA's profit expectation is defined as:

$$U_t^r\left(r'_t, P_t^{CB}, \mu_t\right) = \left(r'_t P_t^R - (1 - r'_t t)P_t^{CB}\right)\mu_t (2)$$

With the condition of restriction$U_t^r\left(r'_t, P_t^{CB}, \mu_t\right) \geq 0$

Then the restriction for P_t^{CB} can be obtained by:

$$P_t^{CB} \leq P_t^R \times \frac{r'_t}{(1-r'_t)} \quad (3)$$

Similarly, the DA's profit expectation is represented by

$$U_t^D\left(r'_t, P_t^{CB}, \mu_t\right) = \mu_t \textstyle\sum_{r_t}\left(\left(\beta - P_t^R r'_t\right) + \left(P_t^{CB} - \gamma\right)(1 - r'_t)\right)\, p\left(r'_t|P_t^{CB}\right) \quad (4)$$

Where restrictions are $0 < r'_t < 1$;$0 \leq p\left(r'_t|P_t^{CB}\right) \leq 1$ and $\sum_{r_t} p\left(r'_t|P_t^{CB}\right) = 1$

3.5 Model Evaluation For Imgn

It is assumed C_1 is the RA' s restriction curve and represented by $P_t^{CB} = P_t^R r'_t /(1 - r'_t)$.Similarly,$C_2$ is RA' s optimal curve and represented by $P_t^{CB} = P_t^R(ar'_t + b(r'_t - 1))\,/2a(1 - r'_t)$ as shown in (Figure 4)

By solving Equation (1) and Equation (2) yields

$$\text{Max}\ U_t^D(r'_t, P_t^{CB}, \mu_t) = \text{Max}\left\{(r'_t P_t^R - (1 - r'_t)P_t^{CB})\left(a\frac{P_t^{CB}}{P_t^R} + b\right)\right\} \quad (5)$$

It is hypothesized that $\frac{\partial U_t^D}{\partial P_t^{CB}}$ exist and according to the classical optimization rules, to maximize the DA's benefit,$\frac{\partial U_t^D}{\partial P_t^{CB}} = 0$ we'll get

$$(P_t^{CB})_1^* = \{(ar'_t + br'_t - b)P_t^R\}/\{2a(1 - r'_t)\} \quad (6)$$

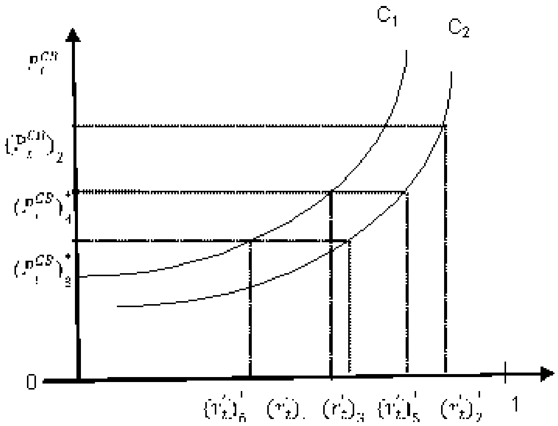


Figure 2 Assumed optimum and restriction curves of IMGN

Therefore

$$(r'_t)^*_1 = (2aP^{CB}_t + bP^R_t)/(2aP^{CB}_t + bP^R_t + aP^R_t) \qquad (7)$$

The DA's estimation is:

$$p\,(r'_t|P^{CB}_t) = \begin{cases} 1, r'_{t=}(r_t)^*_1 \\ 0, r'_{t\neq}(r_t)^*_1 \end{cases}$$

Similarly, the DA's profit expectation is:

$$U^D_t\left((r'_t)^*_1, P^{CB}_t, \mu_t\right) = \mu_t \sum_{r_t}\left(\left(\beta - P^R_t\right)(r'_t)^*_1 + \left(P^{CB}_t - \gamma\right)(1 - (r'_t)^*_1)\right)\left(a\frac{P^{CB}_t}{P^R_t} + b\right) \qquad (8)$$

Bargain probability value is evaluated as

$$(\mu_t)^*_1 = f((P^{CB}_t))^*_1 = a\frac{(P^{CB}_t)^*_1}{P^R_t} + b$$

By assuming that $P^{CB}_t \leq 1$, it is found that
$r'_t \leq (2-b)/(2-b+a)$
Suppose

$$(r'_t)^*_2 = (2-b)/(2-b+a) \qquad (9)$$

By solving Equation (6) and Equation (9), we will get

$$(P^{CB)}_t)^*_2 = (1-b)P^R_t/a \qquad (10)$$

Therefore under the optimum strategy of RA sends the value of $(P^{CB)}_t)^*_2$ as signal when $r'_t(r'_t)^*_2$. Then DA will estimate

$$p\,(r'_t > (r'_t)^*_2|P^{CB}_t) = \begin{cases} 1, P^{CB}_t \geq (P^{CB)}_t)^*_2 \\ 0, P^{CB}_t < (P^{CB)}_t)^*_2 \end{cases}$$

By solving the restriction equations of both RA and DA, we'll get

$$(P^{CB}_t)^*_4 = P^R_t\gamma/\beta \qquad (11)$$

$$(r'_t)^*_4 = (\gamma)/(\gamma+\beta) \qquad (12)$$

When, $P^{CB}_t < (P^{CB)}_t)^*_4$, then

$$(r'_t)^*_5 = \frac{2a\gamma+\beta}{2a\gamma+(a+b)\beta} \qquad (13)$$

Other values are calculated in the same way and summarized below:

RA's Decision Strategy

$$P^{CB}_t = \begin{cases} 0 & 0 < r'_t < (r'_t)^*_4 \\ (P^{CB}_t)^*_4(r'_t)^*_4 \leq r'_t < (r'_t)^*_5 \\ (P^{CB}_t)^*_1(r'_t)^*_5 \leq r'_t < (r'_t)^*_2 \\ (P^{CB}_t)^*_2(r'_t)^*_2 \leq r'_t < 1 \end{cases}$$

DA's Decision Strategy

$$\mu_t = f(P^{CB}_t) = \begin{cases} 0 & ; P^{CB}_t < (P^{CB}_t)^*_4 \\ a(\frac{P^{CB}_t}{P^R_t}) + b & ; (P^{CB}_t)^*_4 \leq P^{CB}_t < (P^{CB}_t)^*_2 \\ 1 & ; (P^{CB}_t)^*_2 \leq P^{CB}_t \end{cases}$$

3.6 Implementation Framework

The implementation of the proposed approach requires a latest infrastructure upgrade at both level of distribution and customer's household i.e. IMNG and houses are smart and equipped with latest technologies. (Figure 5) depicts the implementation of suggested approach in simulation framework. It is assumed that customers within IMGN are willing to deviate their demand from normal consumption to reduced levels for receiving compensated financial benefit. Customers could make a substantial profit, while they would sustain an energy usage reduction. In this section, models for customer's load profiles and renewable energy generation units for the simulation of an IMGN are discussed briefly.

3.6.1 Wind Turbine Modeling

A wind turbine operates by extracting the kinetic energy from the wind passing through its rotor. All parameters become constant except wind speed, the only variable on which the turbine output is dependent for a selected turbine. Therefore, winds speed is modeled by Weibull distributions function to express it as a stochastic process for this work.

$$f(\tau) = \frac{\sigma\tau^{\sigma-1}}{C^\sigma}e^{-(\tau/c)\sigma}$$

Where τ is the speed of wind in meter/s. The parameter σ is defined by $\sigma = (\sigma/\bar{\tau})^{-1.086}$ and c is a measure of characteristic speed at the selected site.

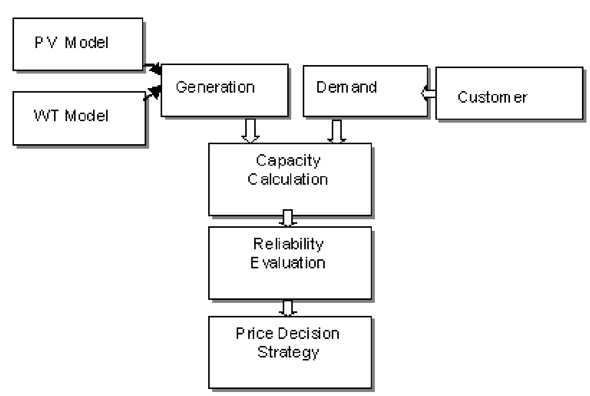


Figure 5 Implementation frameworks for proposed work

$$c = \frac{\bar{\tau}}{\Gamma(1+\frac{1}{\sigma})}$$

Where $\bar{\tau}$ the mean wind speed, σ is the standard deviation, and Γ the absolute gamma function.
The wind power output average (P^w) for every hour can be calculated as follows:

$$P^w = \int_0^{\infty} P^w f(\tau) d\tau$$

Where $P^w$the electric is output of the wind system and can be expressed as below

$$P^w = \begin{cases} 0 & 0 \le \tau_t \le \tau_{c-i} \\ (A + B\tau_t + C\tau_t^2 + D\tau_t^3) & \tau_{c-i} \le \tau_t \le \tau_N \\ P_N & \tau_t \ge \tau_N \end{cases}$$

Where τ_{c-i} and τ_N are cut-in and cut-out wind speeds respectively,τ_t is the actual wind speed at time t, and P_N is rated power of the wind turbine.The generated power remains constant at the rated power output for all the values of wind speeds more than τ_N in a typical design of a wind turbine[28,29]. For the simulation, data is used from the manufacturer of Lagerwey L82 is given below in Table 1.

Table 1 Parameter used for simulation

Parameters	Values
A	18016.98
B	-12908.74
C	2620.05
D	-98.39
τ_{c-i}	2.7 m/s
τ_N	13.8 m/s

Table 2 ToU rates

Patterns	Periods	ToU rates (Unit/kWh)
On peak	10 am-8 pm	2.2
Shoulder	7 am-10 am 8 pm-11 pm	1.8
Off peak	11 pm-7 am	1.6

3.6.2 Photovoltaic's System Modeling

The photovoltaic (PV), being an attractive source of renewable energy, is the appropriate option for electrification in IMGN because of their small size and ease in transportation[30]. The functionality of a solar cell can primarily be understood by considering it as a diode. In the model of a PV cell, the output terminal current (I) and voltage (V) of the cell can be calculated as:

$$I = I_{ph} - I_D - I_{sh}$$
$$V = V_{oc} - IR_s$$

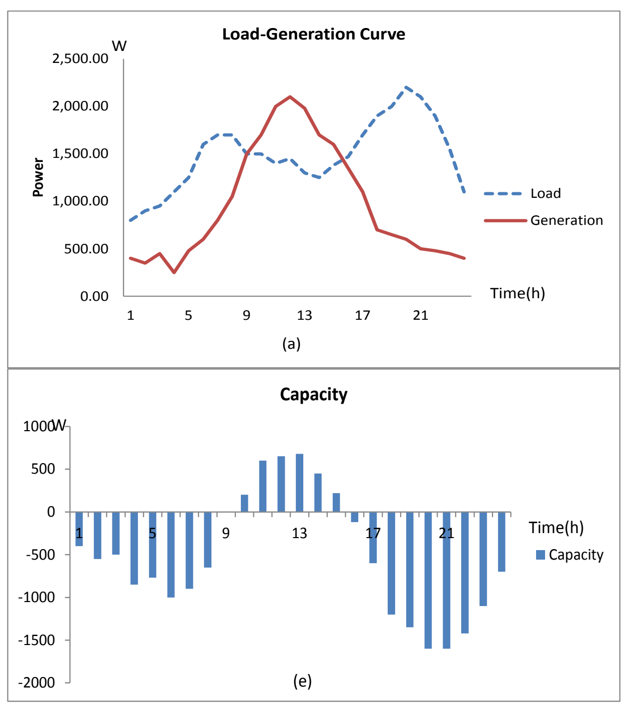
Where I_{ph} is the photon-generated current, I_D is the current passing through the diode, I_{sh} is the leakage current passing through the shunt resistance Rsh whereas, V_{oc} is the open circuit voltage of the cell, which is obtained when the current through the load Rload is zero (i.e. I = 0).

3.6.3 Load Profile Models

Electricity prices can be predicted more accurately if we can better explain the variability of demand. For the purpose of simulation of micro-grid as whole, power consumption profiles of different household appliances are needed. Therefore, realistic consumption profiles models are used for simulation purpose obtained from the RELOAD database[32-34].

■4.0 ANALYSIS OF THE RESULTS

In order to the evaluation of the performance of the proposed model, the peak load curve of an IMGN has been developed. It is observed from this load curve that it can be split into three different regions, called low load period (00:00 am–9:00 am), off-peak period (9:00 am– 5:00 pm) and peak period (5:00 pm–11:00 pm).It is shown in the (Figure 6a) that peak demand load is around 22 kW, whereas the peak renewable generation is merely 21 kW. The reason for this is the highly volatile nature of renewable generations that are dependent on the atmospheric conditions. Furthermore, the peaks of combined renewable generation and total demand load are not arising at the same time. This is because of the generation physics of renewable energies resources. A photovoltaic is more likely to produce peak power during the mid of day; while demand load is usually higher during nights. Thus, causing seriously stability and reliability issues for an IMGN that is the main concern of this research. It is observed that reliability is reduced with the growth of peak load if the power generation are limited and become more pronounced when working in an independent mode. (Figure 6c) shows the decrease in reliability with increase in peak load. When system is under stress, customers can help out the IMGN operator by participating in demand management programs if they are being offered various attractive financial incentives. When the IMGN's reliability changes, the IMGN Controller can instantly adjust its price to reflect the resource state and send signals to DA. It is an effective tool for DA in market oriented DR environment to adjust their load consumption quickly for the safety of system.



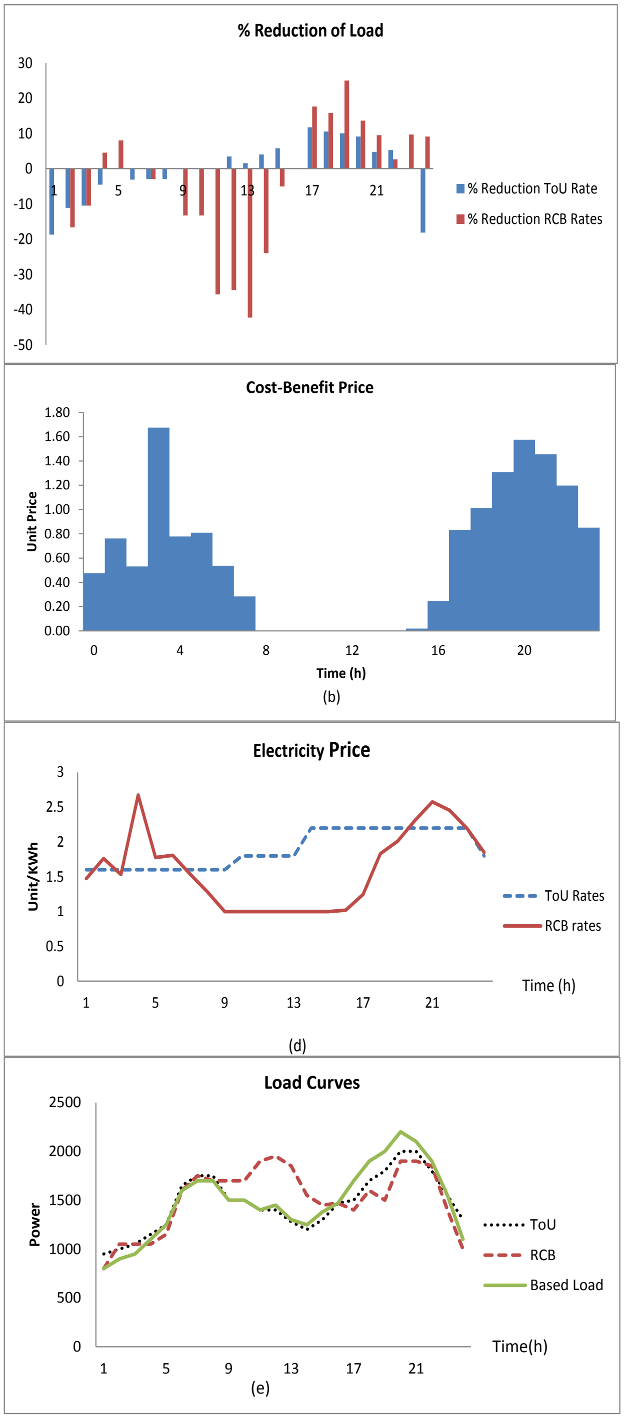


Figure 6 (a) Generation and load curve, (b) Calculated RCB price, (c) Available reserve capacity,(d) Electricity prices,(e)Comparison of ToU and RCB model of simulated IMGN, (f) Reduction of load

More considerable advantage of proposed model is its reduction in computation complexity, its algorithm simplicity and decrease in IMGN's communication expense.

In deregulated electricity market, RA will get the maximum profit when the cost-benefit price is evaluated according to the proposed RCB model. Therefore, this will create new rates pattern based on grid reliability as shown in (Figure 6b &6d).

Many researchers have explored the comparison between ToU rates with of flat rates. It is found that ToU rates provide more attractive incentive to customers for shifting/reducing their loads. Therefore, to investigate the customer's behavior in response to the new RCB price model, it is compared with ToU rates. Table 2 gives more detailed information on specific TOU periods and rates used for simulation. In fact, electricity is inelastic good and not many customers will respond to price changes. Therefore, this study considered an assumption that 100 percentages of customers are willing to shift their loads according to the increase in electricity prices as compared to the other rate.

For simplicity, we assume that this participation function value is constant throughout the day. Above assumption gives a generalized idea to represent the customer behavior.(Figure 6e) illustrates the original household load profiles and the updated load shapes after applying model based DR algorithm under RCB and ToU rates. It is worth noted that, under the RCB rates, on-peak price is 2.6 U/kWh, whereas ToU rate is 2.2 U/kWh. (Figure 6f) shows the percentage (%) reductions of loads under both pricing scheme. It can be observed that at critical time, RCB model gives much better result as compared other rates. This represents roughly 18% increase over the ToU rate. As a result, we can expect that the load levels % reduction with DR under the RBC model is higher than those under the ToU pricing scheme. The pattern shows considerable improvement in system reliability as compare with ToU patterns and shifting of load usage at the time when generation is high. Thus, better utilization of renewable energy resources generation with maximum profit for both players of electricity market (Figure 7). At this point, there is not made any classification and assigned priority to controllable load. It will be considered in future work to add more complexities in the existing work.

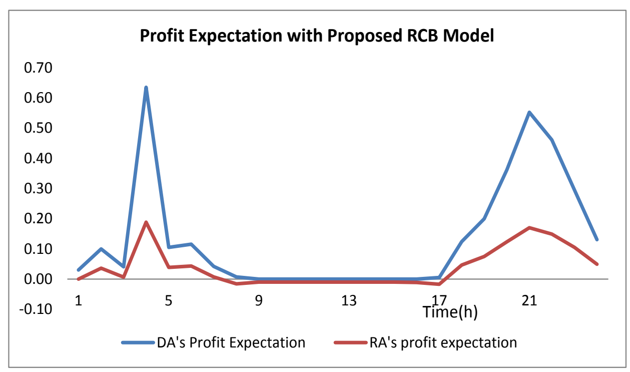


Figure 7 Profit expectation

RCB pricing scheme will create a new peak at around (11:00 am- 3:00pm) which is suitable for better utilization of IMGN resources without deteriorating the reliability issues. To this end, it should be noted that the developed model useful and adaptable to analyze other real-time pricing schemes based on IMGNO's optimal and restriction curves, including those that change every hour, as well as other demand response strategies. It is expected that the developed Reliability based cost-benefit model will benefit utilities and relevant regulatory bodies to analyze the suitability of various type demand response to be used in a smart grid environment and will introduce an automization approach in electricity market .

5.0 CONCLUSION

In this paper an economo-SGT based Reliability Cost-Benefit (RBC) is presented for an independent micro-grid (IMG) community with the consideration on limited generation capacity. It was shown by the result that customer's participation in DRPs depend on the incentive given to the customers by utilities. The theoretical analysis and the simulation results show that how to distinguish the IMGN reliability in new deregulated electricity market and create a mechanism to relate with incentives to attract customer for participation. This is a new innovative idea that can be utilized for different type of DSM. It reduces the calculations and communications related problems significantly. By using the proposed economic RCB model, utilities can simulate the behavior of customers for different operating restriction curves, dynamic incentives, and reliability concerns. In addition, this model can be used for the purpose of improvement of load profile characteristics as well as satisfaction of customers.

The model has some advantages of simple algorithmic calculation, more adoptable with the latest configuration of deregulated market in SG, reducing expenses of computational and the network communication, distributive and dynamic adaptability. When the resource reliability changes the RA can instantly adjust its price to reflect the IMGN's state. Thus causing a preventive measure to control the demand within limits and keep the grid secure. This offers practical market oriented conceptions concerning the different types of energy sources and their penetration levels in order to satisfy the load requirements and load growth for the IMG system. One of the core conclusions that can be drawn in this study is that the determination of cost benefit in real time considering different scenario of operation constraints and geographic locations can also affect the market. The decision strategies presented in this paper should assist the power system engineers to decide on the cost effective operating policies with different types renewable energy resources in an IMG system.

Acknowledgments

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Nomenclature

r_t Reliability of the power system at time t
P_t^{CB} Cost Incentive or Cost-Benefit at time t
$(P_t^{CB})min$ Min value of Cost Incentive or Cost-Benefit at time t
$(P_t^{CB})max$ Max value of Cost Incentive or Cost-Benefit at time t
P_t^R Electricity Price at time t given by resource agent
β Customer's gain in the bidding
γ Customer's loss in the bidding
μt Bargain probability
$U_t^D(r_t, P_t^{CB}, \mu_t)$ Resource agent's profit expectation

$U_t^D(r_t, P_t^{CB}, \mu_t)$ Demand agent's profit expectation
$p\left(r_t \middle| P_t^{CB}\right)$ Estimation probability

DA Demand Agent
RA Resource Agent
IMGN Independent Micro Grid Network
IMGNO Independent Micro Grid Network operator
SGT Signaling Game Theory
DRP Demand Response Program
RCB Reliability-Cost-Benefit
SG Smart Grid

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