A Reliability Insurance Scheme For The Electricity Distribution Grid

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Abstract

Under current regulatory structures, all consumers receive a uniform, average reliability regardless of how much they value their electricity service. Distribution companies (DISCOs) have no direct financial incentives to provide reliability. The resulting reliability standards are arbitrarily determined, with no basis in the actual demand for reliability. In this paper, we examine the benefits of a regulatory scheme that allows for differentiated reliability service based upon consumer's preferences. The proposed scheme involves allowing each customer to choose a type of insurance for reliability based upon their own value for that service. Implementing insurance for reliability will allow consumers to provide economic signals to the distribution provider. These signals enable the distribution provider to make economically efficient investment decisions. The insurance also allocates the risk of outages to the distribution provider (who has control of the system), rather than to the consumers (who have no control). The implementation of reliability insurance provides a relatively simple method for unbundling the delivery and reliability services and enables consumers to receive differentiated reliability service based upon how much they value this service. This paper elaborates upon the proposed reliability insurance scheme and shows how it improves overall social welfare

Keywords: Regulatory Structures, Demand curves, Reliability, Insurance, Risk

I. Introduction and motivation

The inherent weaknesses of current regulatory schemes, including those that utilize penalty functions for reliability service are: a uniform average reliability for all consumers, a single bundled tariff, the lack of efficient economic signals for investments in reliability, and the burden upon regulators to determine the value of service to the consumers. A scheme which allows for consumers to choose a differentiated reliability service based upon their value for energy delivered (or alternatively their cost for energy not delivered) eliminates these weaknesses. A bottom-up approach to reliability, where consumers express their preference, clearly defines the demand curve for reliability and eliminates the need for regulatory approximations. The introduction of insurance for reliability, purchased by the consumers from the DISCO, provides an overall improved structure for efficient management of the grid.

Reliability insurance provides that the DISCO reimburses consumers for energy not delivered (outages) according to the consumers' value, which is specified by the insurance contract. The consumers pay an insurance premium for their selected coverage to the DISCO. This premium may be used to cover the costs of improving reliability or to pay reimbursements.

The reasons for introducing reliability insurance on the distribution grid are numerous [2]. Reliability insurance allows consumers to give the DISCO the proper signal of their value for reliability service and alleviates the risks that consumers currently are forced to accept. The risk is transferred to the DISCO, who as the owner and operator of the distribution grid is able to take actions to control reliability, in contrast to the consumers who are passive recipients of the reliability from the grid. The DISCO, in return, is able to profit from improvements in reliability.

Reliability insurance can be viewed as a form of product differentiation. Consumers willing to pay a higher price are given a higher priority in receiving the service - they receive a product with differentiated quality. In fact, because consumers are free to choose among a menu of different insurance contracts offered by the DISCO, their selection reflects their value for the service. Consumers will choose a policy that correctly reflects their value for service. Therefore an allocation scheme under which DISCO serves consumers in order of their selected priority correctly reflects consumer preference.

Reliability insurance can be used to develop priority restoration schemes, maintenance (such as tree trimming) plans, and rationing schemes for curtailing excess demand in the event of a deficit on the supply side. In each case the DISCO makes decisions and assigns priorities according to the consumers' valuation of the service. Moreover, the same information can be used to guide longer-term investments in terms of capacity and technology upgrades to the grid.

The characteristics of the distribution grid allow for a pricing scheme that allocates services according to consumers' valuation. Recent advances and cost reductions in the technology of metering, control, and communication make the implementation of differentiated reliability feasible. A regulatory scheme that includes reliability insurance will provide incentives for the DISCO to use them

efficiently. The current, uniform reliability is not sufficient for those consumers with higher values for service. Consumers with lower values, on the other hand, are paying for a level of reliability higher than they need. Consumers can choose reliability insurance according to their value for this service, allowing them to pay only for the level of reliability that they desire.

Reliability insurance should be combined with a performance based price scheme for the delivery service. This will allow for the unbundling of the delivery and reliability services. A cost of service based pricing scheme would necessitate the difficult if not impossible task of differentiating between costs for delivery and costs for reliability. Under a performance-based scheme, however, this is not necessary. The initial price cap should be set to allow the DISCO a reasonable return based upon the current delivery and reliability service. The reliability insurance will provide only for future changes in reliability. This eliminates the need for the regulator to differentiate between the costs of delivery and the costs of reliability. The future decisions of the DISCO will be based upon improving the efficiency in the operation and use of the grid.

II. Our model and framework

We consider the distribution utility as an *operator* and *owner* of the distribution grid, which is not involved in any generation activity, or in energy retailing. The distribution utility is responsible for investment in distribution assets and is the monopoly provider of energy delivery service. It also provides reliability, voltage support and other ancillary services. In this paper, we focus solely on delivery and reliability service.

For the case of delivery and reliability service only, a good regulatory scheme gives the DISCO incentives to efficiently manage delivery while at the same time meeting consumers' reliability requirements. Such a regulatory scheme can be designed so that the DISCO's short term decisions concerning the use of existing assets and long term investment decisions are driven by consumers' values for delivery and reliability services.

We measure reliability as the total duration of all outages times the amount of load not served, that is, the total amount of energy not delivered to consumers. This measure is appropriate because from the consumers' point of view the cause of a deficit in the energy provided is not relevant, only the deficit itself. The energy not served, therefore, is an appropriate index, also easily verifiable by consumers themselves. The value of the energy not delivered can be used as an accurate and quantifiable measure of consumer preferences for reliability service.[1]

III. Reliability insurance design

Reliability insurance is based upon the current, easily measured, average reliability. The regulator establishes a standard offer for reliability insurance based upon the average reliability and an estimated consumers' value of service. The only determination that the regulator is required to make is the average value for service. This standard offer is designed such that if every customer chooses it and the DISCO maintains the status quo performance of the grid there is no change in either consumer's surplus or DISCO profitability. That is, the premiums charged for the standard insurance will be equal to the payouts as long as the standard level of reliability is maintained. The DISCO is free to offer insurance contracts for values above and below the standard offer. Consumers with higher or lower values for reliability service will choose the appropriate level of coverage. All consumers will initially receive the standard offer insurance and may select another coverage level if appropriate.

The reliability insurance contracts will require consumers to pay a premium,

$$P=f(\text{reimbursement, quantity, reliability})$$

in advance to obtain a subsequent monetary reimbursement,

$$R=f(\text{value, reliability, quantity}),$$

for the total amount of energy that is not delivered (plus a small amount for administrative costs) [2]. Assuming risk neutrality, the consumers will choose a contract that provides for a reimbursement amount equal to their value for the service. We assume that revenues from the sales of reliability insurance are not used to meet DISCO revenue requirements for covering ordinary fixed and operational costs (this is recovered through the delivery tariff). In this case, the standard offer premium has the simple form

$$P=Q\cdot R\cdot(\text{expected outages})$$

where R represents the reimbursement rate [$/MWh] for each unit of energy Q [MWh] that is not delivered. The expected outages are determined by the average outages for the case of the standard offer.

Efficient pricing of reliability insurance is based on a simple principle: customers require a reimbursement equal to their value, v, for energy (net of price). We can also interpret v as the loss experienced by a

[1] Reliability includes not only the duration of interruptions but also the frequency with which they occur. An extension of the insurance scheme to include frequency of interruptions is relatively straightforward.

consumer because of an interruption. Given that *rel* represents the delivery reliability, consumers will choose the coverage that maximizes their surplus:

$$CS = [v \cdot rel + R \cdot (1 - rel) - P(v, rel)] \cdot Q \qquad (1)$$

In order to minimize the reimbursements payable in each contingency, the DISCO will prioritize delivery service for those customers with the highest values since these will require the largest reimbursements. Moreover, by way of the premium payments, reliability will be associated with the willingness to pay for it by the consumers. The value and cost of reliability service is then unbundled from delivery service for both consumers and DISCOs[2].

IV. Contract Provisions

In order to ensure that the DISCO is not bankrupted by reliability insurance provisions there are several terms that must be included in the contracts. First, the DISCO will not be responsible for outages in generation or transmission. This limits the risk that the DISCO faces to the distribution grid itself.[3] Otherwise, poor management of the transmission grid or a lack of generation capacity could have severe implications on the reimbursements that the DISCO pays. Determining the source of outages to be distribution, transmission, or generation is generally straightforward.

The duration of insurance contracts must be such that they allow for the proper investment signals and prevent consumers from choosing initially high insurance values, only to change to a lower value after the DISCO has invested in equipment to ensure that the consumers' reliability is improved. A good method to prevent this type of gaming is to have long duration insurance contracts with the ability to upgrade the coverage level at any time, but not to downgrade the coverage level arbitrarily. This will enable the DISCO to make investment decisions to upgrade the grid with reasonable certainty of the revenues from the insurance premiums.

Another concern for the DISCO is the case of catastrophic outages related to severe weather events such as a hurricane. Although the DISCO obviously does not have direct control over such events, it is able to take precautions against such events through investments such as moving lines underground. Using the revealed values for the service shown by the insurance coverages selected by its consumers, a DISCO can determine whether or not such investments are economically efficient. At the same time, a DISCO may take out an insurance policy with a large insurance company to prevent such an event from bankrupting the DISCO's reliability fund.

V. Example

The following simple example illustrates the improvement in overall social welfare provided by reliability insurance. Consumers are offered a menu of three choices for coverage and insurance is compulsory (to prevent free riders). A standard contract (S) instituted by the regulator that is associated with the current level of reliability, a high reliability contract (H) and a low reliability contract (L). Consumers choose an insurance contract according to their value for service and receive a reimbursement equal to their expressed value in case of failure to deliver by the DISCO. The insurance scheme requires that the standard contract (premium, value, and reliability level) be set by the regulator in order to avoid overcharges by the DISCO. Since the consumers consequently self select their insurance contract from a menu of choices, the regulator does not need to capture exactly the consumer needs for this particular contract. Its function is to set a benchmark around which the DISCO will set its charges and to make sure that the benchmark premium is reasonable in price. Both consumers and DISCOs obtain an increase in welfare. First we examine consumer benefits and then the DISCO's. Consumer's surplus is given by:

CS = value of energy - price paid for energy

Without insurance:

$$CS = (v \cdot Q) \cdot r_1 \qquad (2)$$

With insurance[4]:

$$CS = (v \cdot Q) \cdot r_2 + [(1 - r_2) \cdot v - P] \cdot Q \qquad (3)$$

$$CS = [v - P] \cdot Q$$

$$\Delta CS = [v - P] \cdot Q - r_1 \cdot v \cdot Q$$

$$= [(1 - r_1) \cdot v - P] \cdot Q \qquad (4)$$

Therefore, if $(1 - r_1) \cdot v > P$, CS will increase.

v - Consumer value ($/MWh),
r_1 - initial (standard) reliability
r_2 - reliability with insurance

Table 1 gives an example menu of insurance coverages. Table 2 shows the change in consumer surplus for various customers choosing a coverage.

The overall welfare of consumers with average (Med) value of service does not change with or without insurance. They will simply receive reimbursements

[2] This is the differential cost of reliability since the costs of current standard reliability are bundled in the delivery charge – it is quite difficult, if not impossible to separate the costs in the current grid.

[3] Insurance can be expanded upward to transmission and generation through DISCOs, ESPs, or consumers purchasing insurance from transmission providers.

[4] Assumes consumers are rational and choose contracts according to their value for service.

equal to their premiums. Consumers with higher or lower values for reliability are better off choosing the contract reflecting their value of service.

Table 1- Menu of insurance coverages

Insurance	Premium – P ($/MWh)	Value - v ($/MWh)	Rel Level
High (H)	0.45	500	99.95%
Standard (S)	0.2	200	99.90%
Low (L)	0.08	100	99.85%

Value, v = Reimbursement; Rel level =expected average reliability for the customers choosing each policy

Table 2 - Change in Consumer Surplus

Insurance	High value ΔCS/q ($/MWh)	Med value ΔCS/q ($/MWh)	Low value ΔCS/q ($/MWh)
H	0.05	-0.1	-0.15
S	0	0	0
L	-0.18	-0.03	0.02

Consumer self-selection results in buyers maximizing their benefit by choosing the contract corresponding to their value of service. For example, the consumer whose value for service is $500/MWh will buy the High Insurance coverage in order to maximize their benefits. There is no incentive to choose a lower coverage, since it will not fully reimburse them for losses in case of outages. In the same manner, consumers that value service at $200/MWh will be better off with a lower level of coverage.

As long as premiums are less than or equal to the expected benefit from reimbursements, consumers will benefit from choosing the insurance that corresponds to their value. If the DISCO does not offer coverage for the consumer's value at a low enough premium level then the consumer can choose the standard offer insurance and will not be any worse off than without insurance. In addition, the consumer will be able to compare the costs of the higher insurance to outside sources of reliability insurance, such as contracting with distributed generation, backup generators, etc and in this way limited competition for the reliability service can be introduced.

A DISCO, for example might be able to contract for backup generation for two or more very high value customers located near one another at a lower cost than any one of the customers would be able to purchase an individual backup generator. In this case, the DISCO could offer the insurance for these very high value customers at a premium lower than the price the customers currently pay for their own backup generators. Currently, customers do not have this option of contracting with DISCOs for differentiated reliability and must develop their own methods for insuring higher than standard reliability.

From the DISCO point of view, the introduction of reliability insurance offers the opportunity to increase profits and provides efficient price signals for operations and investment decisions. In the case where the DISCO offers only the standard insurance, there is no change in the profit of the DISCO (or the consumer surplus). The DISCO will only offer other levels of insurance at a premium that provides for the costs of providing the differential (change from standard) reliability associated with that contract. In this case, the difference between the costs of providing differential reliability to the consumers and the revenues collected from premiums is positive.

The DISCOs' profit formulation is:

Profit = Premiums (P) – Costs of Differential Reliability (C) – Reimbursements (R)

$$\Pi = \sum P_H + \sum P_S + \sum P_L - \left(\sum C_H + \sum C_S + \sum C_L\right) - \left(\sum R_H + \sum R_S + \sum R_L\right) \quad (5)$$

Under the assumption that providing the current level of reliability does not require the DISCO to incur any additional costs, in the case of the Standard insurance scheme the difference between the premiums collected and the expected reimbursements paid is zero:

$$\Pi = (0.2\$/h) - (200\$/h)(1-0.999) = 0 \quad (6)$$

For the other two cases in the example in Table 2, in order for the DISCO to break even, the costs of providing differential reliability can be computed as follows:

- High reliability case:

$$\Pi = 0 \Leftrightarrow premium - (\$500/MWh)(1-0.9995) = 0$$

$$\Rightarrow premium = 0.2\,\$/MWh$$

- Low reliability case:

$$\Pi = 0 \Leftrightarrow premium - (\$100/MWh)(1-0.9985) = 0$$

$$\Rightarrow premium = -0.15\,\$/MWh$$

In the low reliability case, we obtain a negative result indicating the savings necessary from allowing reduced reliability for those customers for whom the standard level is too high.

The DISCO will make a profit as long as it is able, on average, to provide the expected levels of reliability for less than the net costs indicated above. In this case, the DISCO must be able to increase the reliability of the high value customers from 99.90% to 99.95% at a cost of less than $0.2/MWh. It also must be able to save $0.12/MWh by allowing for a reduction from 99.90% to 99.8% for customers with low value for service. The DISCO can profit from efficient investments in providing differentiated

reliability to consumers according to the consumer's values for the service.

DISCOs will set premiums as follows:

$$\text{Premium}_i = v_i(1-r_i)+C_i \quad i=\{H,L,S,...\} \quad (7)$$

r_i is the expected reliability associated with each contract and C_i is the associated cost.

It is necessary for the regulator to set the Standard insurance offer according to the average value for service and the current average level of reliability. The resultant premium will be:

$$Premium_S = v_S(1-r_S);\ r_S = current\ reliability \quad (8)$$

The regulator should be able to make a sufficiently accurate estimate of the average value for service. This value does not need to be perfectly determined, since consumers can purchase contracts other than the standard.

The consumers' preferences will reveal the correct value of reliability on the distribution grid. Both consumers and DISCOs can benefit from the implementation of reliability insurance.

VI. Implementation

From the DISCO perspective, the transition from the current methods of managing the grid to implementing reliability insurance requires including the expected reimbursements in investment decisions. The DISCO will determine the levels of reliability to provide for each customer based on the costs of reliability and the reimbursement payments.

The following example shows that the DISCO will have incentives for maintaining reliability and investing in efficient reliability improvements based upon the consumers value (in addition to the cost minimization incentives provided by the PBR).

Table 3 - Example Insurance breakdown (one season - 2160 hrs)

Coverage	Premium ($/MWh)	Reimbursement ($/MWh)	Load (MW)	Premium Collected
Standard	0.2	200	5	$2,160
High	0.45	500	2.5	$2,430
Low	0.08	100	2.5	$432

Given the distribution of insurance shown above, the DISCO determines (via investments, maintenance, restoration schemes, etc) the expected reliability to provide each customer group. We examined the following four options and their affect on the profits of the DISCO:

Table 4 - Insurance options

Options:	Rel1	Rel2	Rel3	Rel4
High Customers	99.90%	99.95%	99.85%	99.95%
Standard Customers	99.90%	99.95%	99.85%	99.90%
Low Customers	99.90%	99.95%	99.85%	99.85%

Calculating the effects of each option on the DISCO's expected profits compared to the expected DISCO profits without the insurance scheme illustrates the affects on DISCO decisions. First, the expected profits for each reliability option are calculated assuming no changes in cost to the DISCO (Row 2). This result is then compared to the expected profit with no insurance scheme (Row 1) to determine what the breakeven cost of offering each option would be for the DISCO (Row 3)[5].

Table 5 - Expected profits

Decisions:	Rel1	Rel2	Rel3	Rel4
None	$3,508.41	N/A	N/A	N/A
Insurance	$3,130.41	$5,872.20	$388.61	$3,950.86
Breakeven C_{rel}	-$378.00	$2,363.80	-$3,119.80	$442.45

This table shows that the DISCO will lose money (compared to the no insurance case) if it does nothing (Rel1). If the DISCO is able to maintain the standard reliability for all customers while reducing costs by more than $378, however, the DISCO will increase its profits. The DISCO has a strong incentive not to allow the standard reliability to fall below the standard level. The third option (Rel3) shows that the DISCO must be able to save more than $3000 from cost cutting measures that would result in only a 0.05% reduction in the reliability for all consumers[6]. For a uniform increase in reliability (Rel2), the DISCO's expected profit will be greater than in the base case if the cost of implementation is less than $2,363.80. In the final case (Rel4), the DISCO provides each customer exactly the reliability specified by their insurance contract. The combination of the costs for improving the reliability of some, minus the savings associated with reducing the reliability of others, must be less than $442.45 for the DISCO to increase profits. This differentiation may be accomplished by measures as simple as assigning restoration priority to the high value customer or increasing tree trimming on the lines serving the high value customer.

The DISCO will evaluate the costs of offering the differentiated reliability to determine the most efficient operations and investments, including technological upgrades and the development of restoration schemes.

VII. Consumer aggregation

To efficiently manage the grid with reliability insurance, a DISCO can utilize consumer aggregation

[5] Assumes a price of $60/MWh

[6] Once the consumers have purchased insurance coverage equal to their value for reliability, they are indifferent between receiving service and receiving a reimbursement. Thus, they are indifferent to the actual reliability level they receive

to make decisions at all levels of the grid. Differentiation can occur at any physically separable areas of the grid, and is not limited to the lowest consumer level.

The resulting DISCO objective function is:

$$\max \Pi = Rev - C =$$
$$= \bar{P} Q_{tot} + \sum_i P_i \cdot Custom_i - C - \sum_i R_i \quad i = S,L,H \quad (9)$$

Where:

Rev is revenues;

C is total costs (fixed and variable);

$\bar{P}$ electricity price per kWh;

Q_{tot} total amount of energy transferred by DISCO during that season;

R_i reimbursements for all outages.

At the beginning of a season, the DISCO determines the value for reliability at each level of aggregation according to the insurance. The DISCO can then develop maintenance, restoration, and other operational plans to minimize reimbursement payments. The DISCO can differentiate reliability according to consumers' preferences at the household level or at higher levels. For example, distinguishing a residential area from an industrial area with different values for service.

Consider a radial distribution grid. The DISCO will provide differentiated reliability level at the end user level if it is economically efficient. Otherwise, if the DISCO can provide differentiated reliability at the feeder level for a lower cost, consumers will be aggregated according to the average reliability contracted at that level. The DISCO will simply calculate the sum of the reimbursement levels for every customer on each branch of the feeder, and provide a higher level of reliability to the branch that demands higher reimbursements. The DISCO will maximize its profits by providing the service that mostly efficiently matches consumer preferences.

VIII. Conclusions

Implementing reliability insurance on the distribution grid provides a regulatory enhancement to performance-based regulations with penalties. It provides incentives for the optimal use of the grid according to consumers' value for service. The choice of coverage level reveals the consumers' values for service, giving DISCOs incentives for efficient investment and management of the distribution grid. Outage risk is shifted from consumers, who have no ability to control the outages, to the DISCO, which influences reliability through its investment and operational decisions.

The insurance scheme also unbundles delivery and reliability services at the distribution level and allows consumers to compare the costs of other methods of improving reliability such as purchasing backup generation. Differential reliability service will allow consumers to pay for only the level of reliability they choose, no more and no less.

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