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AN APPROACH TO RISK ASSESSMENTS FOR RE-REGULATED DISTRIBUTION SYSTEMS

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ABSTRACT
In an attempt to re-regulate the distribution segment of an electric power system, public utility commissions (PUCs) are increasingly adopting a reward/penalty framework in order to guarantee acceptable electric supply reliability. This reward/penalty framework is commonly known as performance based ratemaking (PBR). A PBR framework is introduced to provide distribution utilities with incentives for economic efficiency gains in the competitive generation and transmission markets. A distribution utility's historical reliability performance records could be utilized to create practical PBR mechanisms. This paper presents actual reliability performance history from two different Canadian utilities used to develop PBR frameworks for use in a re-regulated environment. An analysis of financial risk related to historic reliability data is presented by including reliability index probability distributions in a PBR plan. In addition, this paper identifies a number of factors and issues that should be considered in generating a PBR plan for a distribution utility. A brief analysis of cause contributions to reliability indices also is performed and presented in this paper. The historic reliability based PBR framework developed in this paper will find practical applications in the emerging deregulated electricity market.

KEY WORDS
Distribution system, deregulation, performance based rate, reward /penalty, historic reliability

1. Introduction

Electric industry has been deregulated in many jurisdictions since late 1980s in an attempt to develop a competitive electricity market for power generation and transmission services. In deregulated markets, the distribution segment of the power supply system has been re-regulated in order to guarantee that the electric service received by customers is reliable, and the distribution system is planned, operated and maintained adequately and efficiently. Public utility commissions are increasingly turning to distribution system reliability performance based regulation (PBR) in order to guarantee electric service reliability in competitive markets [1]-[3]. The basic objective of a PBR framework is to provide distribution companies with incentives for economic efficiency gains, and concurrently discouraging distribution utilities from compromising supply reliability while pursuing economic profits.

The distribution system historic reliability performance information is extremely useful in the sense that it renders invaluable reference in initiating a performance based mechanism. This approach has been utilized by a number of public utility commissions in the United States, Canada, Australia, Great Britain and many other countries. Most of the PUCs utilize distribution system historic performance to establish specified electric supply reliability standards, and also require that electric utilities maintain at least two to five years of reliability performance data in order to remain within the range of their historic system reliability performance levels.

Virtually all PUCs who adopted performance based regulation introduced a reward/penalty structure to encourage distribution utilities to maintain acceptable reliability levels in the new competitive deregulated environment. In the new market environment, the performance based regulation presents local distribution utilities with incentives to operate efficiently, and to innovate in system planning, design, operation and maintenance. At the same time, a PBR also introduces a potential financial risk to distribution companies due to the uncertainty with future system reliability performance.

Canadian electric utilities have a long history of collecting and reporting information on the levels of electric service reliability to their customers [4]. This paper presents some selected historical data for two disparate Canada utilities that have been maintaining the system reliability information for over two decades. Reliability index probability distributions are developed from the actual system reliability performance data, and are used to demonstrate the potential financial risks related to prescribed reward/penalty frameworks. The selected reliability performance data are also categorized into the difference cause codes and presented to display the historic contributions from these causes to service reliability. This paper will prove very useful for distribution companies that are subject to performance based regulation in the re-regulated environment, and will find practical applications in designing a utility specific PBR plan.

2. Cost of Service Regulation versus Performance Based Regulation

Traditionally, rates that electric utilities charge are based on the cost of generating, transmitting and delivering electricity to its customers' point of utilization. For fulfilling their obligation to serve customers in a particular service territory, utilities were guaranteed by PUCs a reasonable return on their investments in the utility infrastructures. Utilities normally designed their systems to very conservative and expensive design standards in the cost service regulation framework. Under the traditional cost of service regulation plan, utilities aggressively handled reliability problems knowing that the costs could be recovered. Deregulation of the electricity market changed everything.

In order to be competitive, utilities are reducing costs by deferring or canceling capital projects and by increasing maintenance intervals. As a result, the reliability on these utility systems is starting to deteriorate. Regulatory agencies are well aware that competition might have a negative impact on system reliability. Competition in the electric power industry provides incentives for enhanced performance, but is not the complete solution for a number of reasons. First, of the three segments of an electric power system, only generation is being opened up to competition. In certain jurisdictions, few for profit transmission companies have been established. Majority of transmission and all of distribution are still being regulated.

Customers are connected to a regulated distribution system that determines system reliability experienced by the customers. As customers of regulated systems, customers cannot switch distribution systems at their will if reliability becomes unacceptable. For this reason, regulatory agencies are looking for ways to define and establish distribution reliability standards, and more and more utilities are finding themselves subject to performance based regulation. The basic steps associated with the traditional cost of service regulation are as follows: (1) utility report costs, (2) regulators audit costs, (3) regulators set rates to enable utility to recover costs plus a fair rate of return on the used and/or useful capital invested, and (4) rates are periodically adjusted to reflect market and cost conditions. The basic steps related to the performance based regulation are: (1) performance requirements such as price, reliability standards are set more or less independent of costs, (2) utilities invest in profitable cost reduction programs and improve efficiency and (3) utilities keep all or part of the increased profits.
The main effects of the cost the service regulation are: (1) rates held at the market rate, (2) profits are proportional to rate base, (3) if prudent, cost increases result in increased rates, (4) cost reductions result in rate reductions and (5) costs drive prices. On the other hand, the main effects of performance based regulation are: (1) efficiency improvements are rewarded as higher profitability, (2) inefficiency is penalized as lower profitability and (3) as opposed to the cost of service regulation, prices drive costs in the PBR plan. Efficiency incentives in the cost of service regulation regime are in general weak if utility management is motivated by profits. In the PBR plan, efficiency incentives are strong if utility management is motivated by profits.

3. A Reward/Penalty Structure in the Performance Based Rates

A PBR is a contract between a PUC and a utility that rewards a utility for providing good reliability and /or penalizes a utility for providing poor reliability. Performance is normally based on average customer interruption information at the system level or at the customer level. This usually takes the form of system level reliability indices such as SAIFI (System Average Interruption Frequency Index) and SAIDI (System Average Interruption Duration Index). These indices are computed using the following equations [5]:

$$\textbf{SAIFI} = \frac{\text{Number of customer sustained interruptions}}{\text{Number of customers served}} \quad \text{per year} \qquad (1)$$

$$\textbf{SAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Number of customers served}} \quad \text{hours per year} \qquad (2)$$

A normal approach to implementing a performance based rate is to have a "dead Zone" where neither a penalty nor a reward is assessed. If reliability is worse than the dead zone boundary, a penalty is assessed. Penalties increase as reliability worsens and are capped when a maximum penalty is reached. Similarly, if reliability is better than the dead zone boundary, a reward is assessed, and the reward grows as reliability increase and capped at a maximum value.

A reward/penalty structure (RPS) integrated in a PBR plan is illustrated in [6] for a Californian utility. This particular PBR performance incentive framework includes three ranges, upper, middle and lower, for the annual SAIDI reliability index. This particular RPS is structured in the following manner:

Upper Range: Penalty - \$1M per 1 SAIDI minute above 65 minutes up to \$18M at 83 minutes and above.

Dead Zone: No reward or penalty – from 53 minutes SAIDI to 65 minutes of SAIDI

Lower Range: Reward - \$1M per 1 minute SAIDI below 53 minutes and up to \$18M at 35 minutes and below. A common method of implementing a RPS in a PBR plan is depicted in Fig. 1 using the data given in [6].

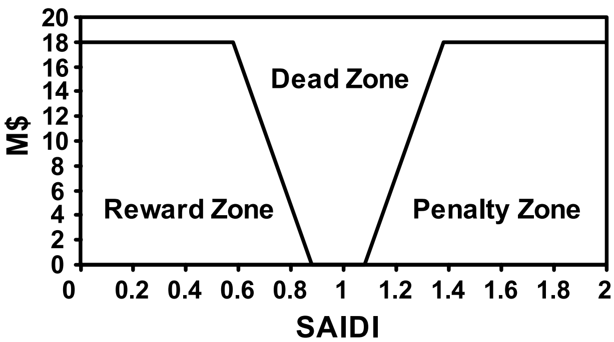

Fig. 1: A general reward/penalty rate structure

As shown in Fig. 1, this performance based rate structure has a "dead zone" from the SAIDI value of 53 minutes to 65 minutes, where neither a penalty nor a reward is assessed. The RPS depicted in Fig. 1 can be expressed by a mathematical model, as shown in Equation (3). The financial penalty due to poor reliability associated with a reward/penalty structure can be computed by combining this RPS with related service reliability index expressed in the form of a probability distribution. The expected system reward/penalty payments could include both SAIFI and SAIDI contributions, and are given by Equations (4), and (5). The reward and penalty payments are computed as:

$$RP \text{ or } PP = f\,(\text{Reliability Index}) \tag{3}$$

$$ERP = \sum RP_i * P_i \tag{4}$$

$$EPP = \sum PP_i * P_i \tag{5}$$

where, RP is reward payment, PP is penalty payment, RP_i is the reward payment at $SAIFI_i$ or $SAIDI_i$; PP_i is the penalty payment at $SAIFI_i$ or $SAIDI_i$; and P_i is the system probability of $SAIFI_i$ or $SAIDI_i$.

ERP and *EPP* are expected total reward and penalty payments, respectively.

Equations (4) and (5) indicate that the reward/penalty structure dictates the utility expected reward/penalty payments. It is therefore important that the reward/penalty policies should be designed with extreme care in order to encourage distribution utilities to maintain reliability levels in the dead zone. For example, if the RPS is designed using a single point long term average estimate for SAIFI or SAIDI without a dead zone, the utilities will be subject to frequent penalty payments due to the variability of annual system reliability performance. This situation is depicted in Fig. 2.

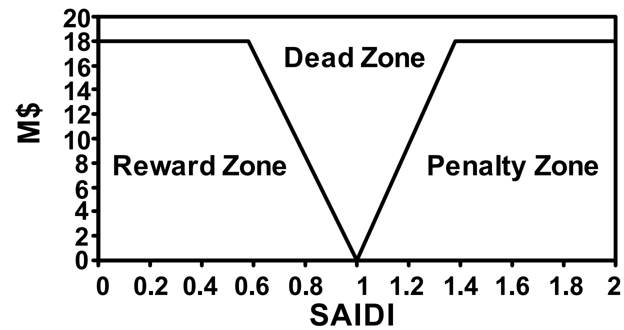

Fig. 2: A reward/penalty structure without a dead zone

Figure 2 dictates that in order to design a PBR framework, the historical average reliability indices such as SAIFI and SAIDI should reside in the dead zone of the proposed reward/penalty structure, and ideally in the middle of the dead zone. The dead zone spread should be related to the standard deviation of the SAIFI and SAIDI indices. The dead zone was set at ±1 standard deviation in the studies presented in this paper. The impact of dead zone width on the reward/penalty structure was investigated using the ±2 standard deviations. The utilities and the public utility commissions can negotiate the proper band width for the dead zone of the RPS using utility specific reliability performance and system characteristics. The financial parameters for reward and penalty in the PBR plan should be related to the incentive strategy established by the public utility commissions.

4. Historical SAIFI and SAIDI Data and their Distributions

The Canadian Electricity Association maintains a comprehensive service continuity outage database on behalf of the Canadian reporting utilities. The service continuity report on distribution system performance in Canadian electric utilities is published annually. The CEA report presents annual reliability indices such as SAIFI and SAIDI, including the interruption cause contributions to the overall reliability indices for the participating utilities.

Table 1 and 2 show the annual SAIFI and SAIDI indices for two disparate integrated (IU) and urban (UU) Canadian utilities for the ten year period from 1995 to 2004, respectively. For the purposes of this paper, an integrated utility includes rural, urban, and mixture of urban/rural systems. The particular utility has long stretched transmission lines from south to north and is a voltage-constrained system. Its crew centers are scattered all over the service territories unlike an urban utility such as City of Winnipeg, York Hydro, Edmonton Power, etc. The integrated utility is a low load density system. The urban utility is large urban system with a relatively low circuit ratio and relatively high load density. The integrated utility has a relatively high load density. The Urban system have short supply feeders, underground circuits and alternate power supplies, while the integrated urban and rural systems have mixture of short and long supply feeders, overhead circuits, and dedicated power supplies. The identity of these utilities is unknown as per company confidentiality rules.

Table 1
System Performance - SAIFI

Year	Integrated Utility	Urban Utility
1995	3.08	1.21
1996	3.15	1.32
1997	3.52	1.16
1998	4.17	1.26
1999	2.68	1.20
2000	3.02	1.17
2001	2.40	0.99
2002	2.53	1.35
2003	2.35	1.46
2004	2.35	1.25
Average	**2.925**	**1.237**

Table 2
System Performance - SAIDI

Year	Integrated Utility	Urban Utility
1995	4.62	2.03
1996	3.78	2.21
1997	4.58	1.88
1998	6.67	2.05
1999	3.73	1.69
2000	4.42	1.93
2001	3.43	1.58
2002	3.85	1.65
2003	4.62	1.81
2004	4.09	1.84
Average	**4.379**	**1.867**

Table 3 shows the average values of SAIFI and SAIDI and their standard deviations for each utility system based on the ten-year historical data.

Table 3
System Performance – Average Values and Standard Deviations

System Type	SAIFI		SAIDI	
	Ave	S. D.	Ave	S. D.
Integrated Utility	2.925	0.560	4.379	0.863
Urban Utility	1.237	0.114	1.867	0.186

As shown in Tables 1 and 2, there are only ten years' SAIFI and SAIDI values in this analysis. Histograms of these data have been developed and combined with the reward/penalty structure to create a PBR plan. The fundamental assumption made in this investigation is that each system remains virtually constant over the period of study in regard to design, maintenance and operational changes. Obviously, this is a gross assumption, and therefore, the histograms for these indices provide approximate probability distributions of the indices. The historical SAIFI and SAIDI data however contain important information on the variation in the annual SAIFI and SAIDI indices, and provide an insight into the variation that can be expected in later years.

5. Computation of System Risks Based on Historical Reliability Indices

In the reward/penalty structure of the performance based regulation plan, the average historic values of the SAIFI and SAIDI should ideally be located in the middle of dead zone. The dead zone width would have impacts on the reward or penalty payments for a particular year reliability performance of a utility. The sensitivity analysis of the dead zone width was performed using the ±1 and ±2 standard deviation of the SAIFI and SAIDI indices in the following studies. This method was used to create the dead zones shown in Tables 4 and 5 for ±1 and ±2 standard deviation respectively, using the historical data for the 1995-2004 period for the two disparate Canadian representative utility systems.

Table 4
The Dead Zones Using ±1 Standard Deviations for the Two Canadian Representative Utilities

System Type	Dead Zones			
	SAIFI		SAIDI	
Integrated Utility	2.365	3.485	3.316	5.242
Urban Utility	1.123	1.351	1.681	2.053

TABLE 5
The Dead Zones Using ±2 Standard Deviations for the Two Canadian Representative Utilities

System Type	Dead Zones			
	SAIFI		SAIDI	
Integrated Utility	1.805	4.045	2.653	6.105
Urban Utility	1.009	1.465	1.495	2.239

Figures 3 to 10 show the combination of the historical SAIFI and SAIDI data for the two Canadian systems and four hypothetical reward/penalty structures. An infinite number of possible RPS could be designed using the historical information. The main focus in this analysis is on the determination of the appropriate location of the dead zone rather than on the computation of the expected reward or penalty payments.

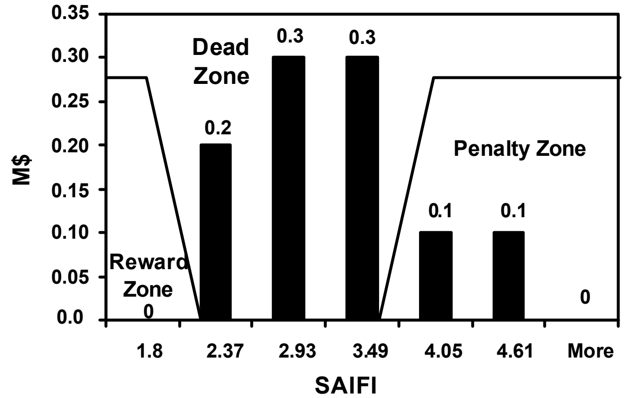

Fig. 3: Combination of the SAIFI histogram with ±1 standard deviation and a hypothetical reward/penalty framework for the integrated utility (IU).

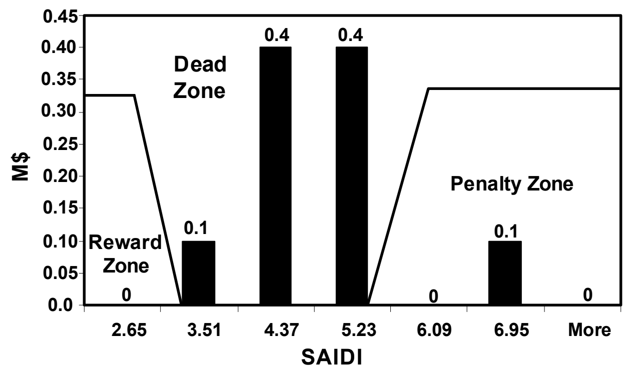

Fig. 4: Combination of the SAIDI histogram with ±1 standard deviation and a hypothetical reward/penalty framework for the integrated utility (IU)

In Figure 3, for the integrated utility with ±1 standard deviation of historical average value of SAIFI, there is a 20% probability that the system SAIFI will lie in the penalty zone. The system SAIDI has 10% probability of residing in the penalty zone in Figure 4. Both structures presented in Figures 3 and 4, show that the utility's performance does not qualify for reward payments. The utility should expect some future penalty payments according to the historic performance. It can be seen from Fig. 3 and 4 that the forty percent outcomes are close to the penalty boundaries. The utility should make improvements which would move its performance towards the center of the dead zone and avoid financial penalties from the regulator.

Figure 5 indicates that for the urban utility with ±1 standard deviation of historical average value of SAIFI, there is 10% probability of reward payments and 20% probability of penalty payments. Figure 5 also reveals that 30% outcomes are close to the penalty boundaries. In Figure 6, for the urban utility with ±1 standard deviation of historical average value of SAIDI, there is a 20% probability that the system SAIDI will lie in the reward zone, and 50% outcomes will lie in the penalty zone. The variability in individual year's performance subjects the utility to some financial penalties in the future unless improvements are made. The utility faces financial risks in the new PBR regime due to the considerable variation associated with its past performance. The utility could possibly earn rewards by making improvements.

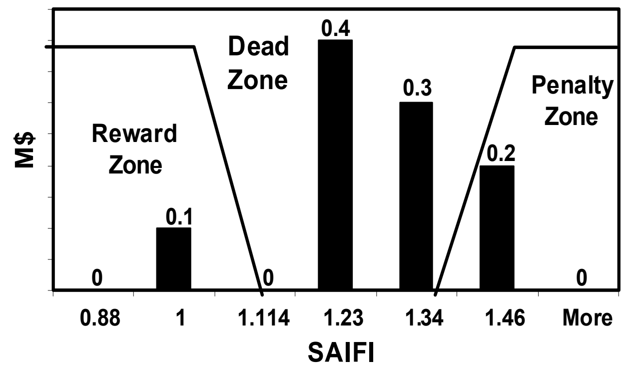

Fig. 5: Combination of the SAIFI histogram with ±1 standard deviation and a hypothetical reward/penalty framework for the urban utility (UU).

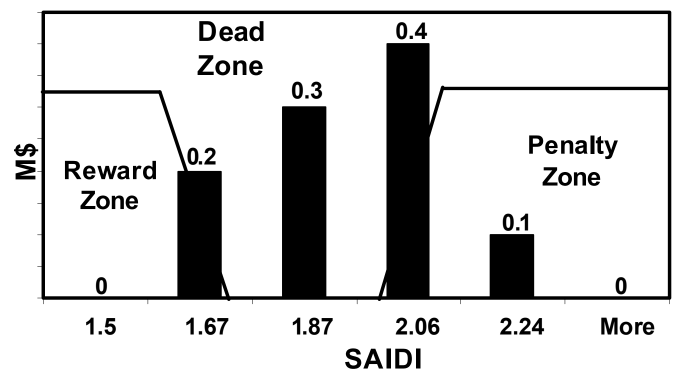

Fig. 6: Combination of the SAIDI histogram with ±1 standard deviation and a hypothetical reward/penalty framework for the urban utility (UU)

It can be seen from Figure 5 and 6 that the forty percent of SAIFI outcomes and 30% of SAIDI outcomes lie in the center of the dead zones. The urban utility should make significant system improvements which would move its performance towards the center of the dead zone and avoid financial penalties from the regulatory commissions.

The impact of dead zone width on the reward penalty structures was investigated by setting the dead zone at ±2 standard deviation for both SAIFI and SAIDI indices. Fig. 7 and 8 show the combination of the SAIFI and SAIDI distributions with ±2 standard deviation and the hypothetical RPS for the integrated utility, respectively.

Figures 9 and 10 shows the combination of the SAIFI and SAIDI distributions with ±2 standard deviationS and the hypothetical RPS for the urban utility, respectively.

Figures 7 and 8 show that 10% of SAIFI and SAIDI outcomes for the integrated utility lie in the penalty zone for the RPS with ±2 standard deviation. The sixty percent of SAIFI outcomes and eighty percent of SAIDI outcomes lie in the center of the dead zones. Fig. 9 and 10 show the RPS for the urban utility with ±2 standard deviation. For both SAIFI and SAIDI indices, the RPS with ±2 standard deviation indicates that the urban utility reliability performance will lie in the dead zone areas. A significant outcome for the reliability performance for the urban utility lies close to the penalty zone and none lies in the reward zone. It is however important to note that the width of the dead zone has significant impact on the reward penalty structures and utilities and regulators should pay close attention to this aspect of the PBR plan.

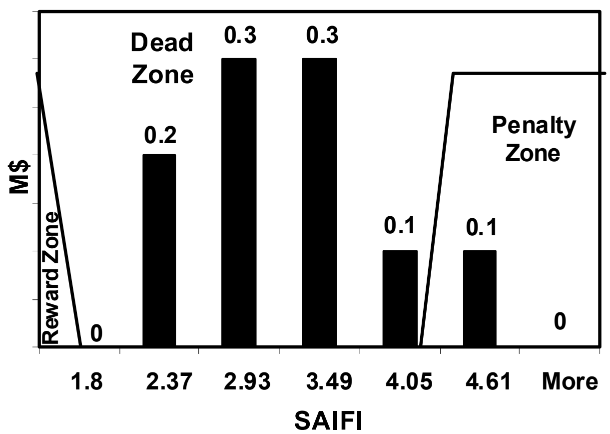

Fig. 7: Combination of the SAIFI histogram with ±2 standard deviation and a hypothetical reward/penalty framework for the integrated utility (IU).

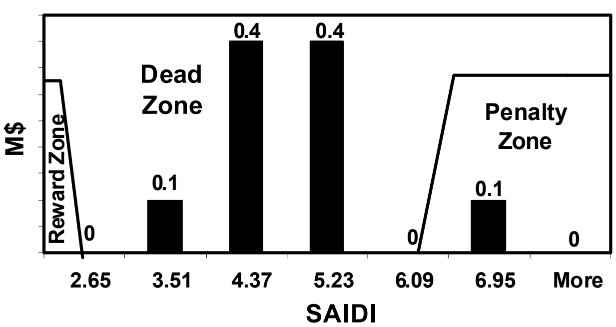

Fig. 8: Combination of the SAIDI histogram with ±2 standard deviation and a hypothetical reward/penalty framework for the integrated utility (IU)

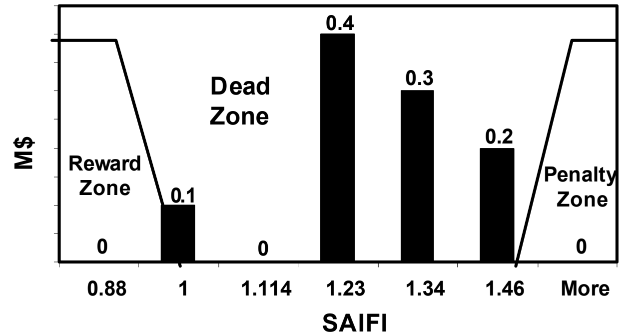

Fig. 9: Combination of the SAIFI histogram with ±2 standard deviation and a hypothetical reward/penalty framework for the urban utility (UU)

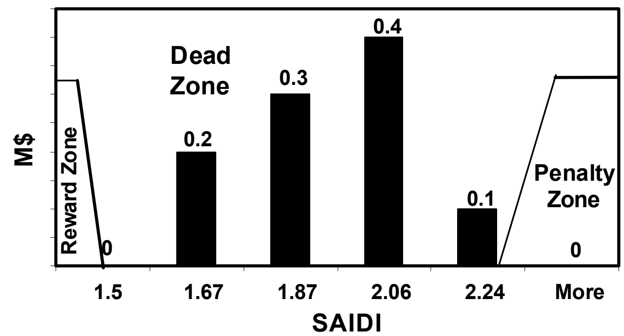

Fig.10: Combination of the SAIDI histogram with ±2 standard deviation and a hypothetical reward/penalty framework for the urban utility (UU).

The methodology used to develop the dead zone values shown in Table IV provides a consistent framework to create the upper and lower bounds based on the utility past performance. The decision to use ± 1 or ± 2 standard deviation is arbitrary and should be studied by both the utility and the regulator. As shown in Fig.2, a single point RPS for a system with no or short operating history would result in relatively high financial risks due to the fact that there is no prescribed dead zone. It is obvious that in these cases, statistically significant historical data are required to create a reasonable dead zone.

It can be seen from the results presented in Fig. 3 to 10 that extreme care is required to develop appropriate dead zone width for both SAIFI and SAIDI. The band width should not unduly penalize a utility and should provide appropriate incentives to encourage a utility to improve its reliability performance. As illustrated in this paper, a reward/penalty structure based on the distributions associated with historical utility SAIFI and SAIDI indices could enable the investigation of the potential financial risks to a utility and provide a consistent framework to performance based regulation.

6. Causal Analysis of SAIFI and SAIDI Indices

The system reliability characteristics of individual utilities differ due to the differences in service areas, load densities, system topologies, weather environments, company management philosophies, and service standards, etc. Urban systems usually have short supply feeders, underground circuits, and alternate power supplies. Their reliability indices are, in most cases, better than those in rural systems.

An investigation of the causal contributions to SAIFI and SAIDI indices from various system factors provides considerable insight into how the system performance can be improved to avoid financial penalties in the new PBR regime. The Canadian utilities divide the customer outages into the following codes: Unknown, Scheduled Outage, Loss of Supply, Tree Contact, Lightning, Defective Equipment, Adverse Weather, Adverse Environment, Human Element, and Foreign Interference.

The major contributions to the service annual SAIFI and SAIDI indices can come from quite different causes in urban and integrated systems. This section presents the major interruption contributions for the two utility systems over the 1995-2004 period.

Fig. 11 presents causal contributions to the annual SAIFI index for the integrated utility (IU). Fig. 12 presents causal contributions to annual SAIDI index for the integrated utility (IU). Fig. 13 presents the causal contributions to the annual SAIFI index for the urban utility (UU), and Fig. 14 presents the causal contributions to the annual SAIDI index for the urban utility (UU).

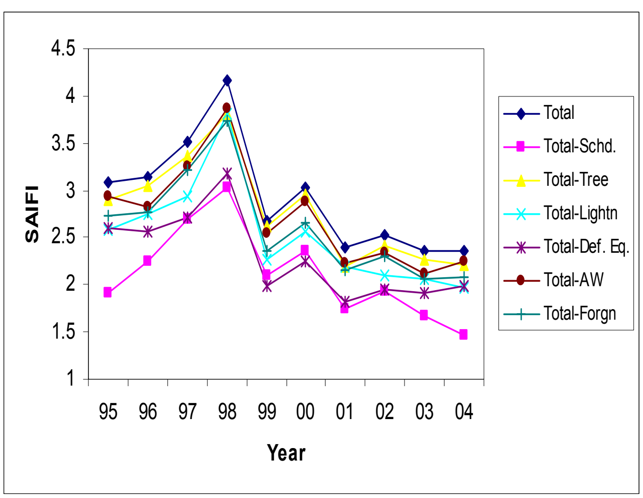

Fig. 11. Causal contributions to SAIFI of the integrated utility (IU)

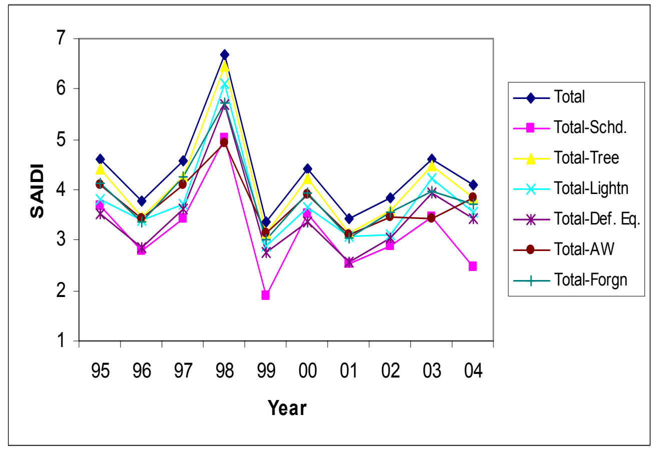

Fig. 12: Causal contributions to SAIDI of the integrated utility (IU)

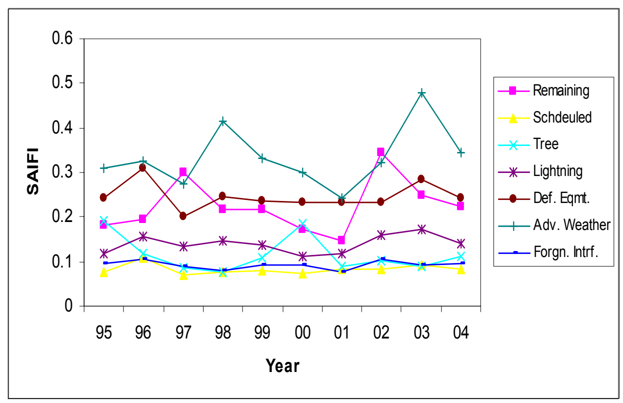

Fig. 13: Causal contributions to SAIFI of the urban utility (UU)

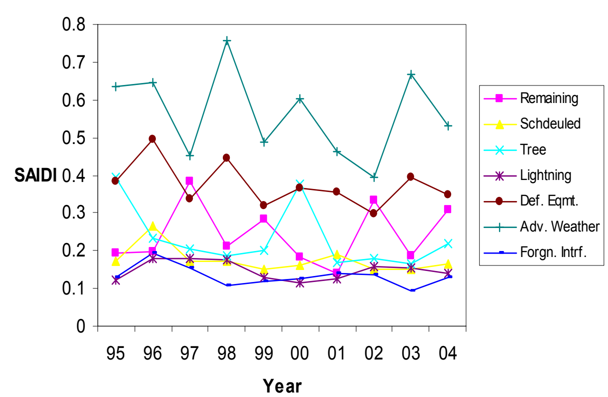

Fig. 14: Causal contributions to SAIDI for the urban utility (UU)

The curves designated as Total, T-Schd, Total-Tree, Total-Lightn, Total –Def. Eq, Total-AW and Total-Forgn represent the annual index, the annual index excluding the contribution from scheduled interruptions, the annual index excluding the contribution from tree related interruptions, the annual index excluding the contribution from lightning related interruptions, the annual index excluding the contribution from defective equipment, the annual index excluding the contribution from adverse weather related interruptions and the annual index excluding the contribution from foreign interference, respectively.

The contributions from interruption causes such as human error, adverse environment, loss of supply and unknown causes are insignificant compared to the contributions from earlier noted causes, and therefore, contributions to SAIFI and SAIDI indices from these causes are not illustrated in Fig. 11 to 14. It can be seen that scheduled outage, defective equipment, adverse weather, lightning and tree related interruptions are major contributors to annual SAIFI and SAIDI indices for both utilities in the ten year period. A knowledge base of primary contributing causes of service interruptions would permit a utility to identify appropriate system improvement plans to avoid penalty payments in the emerging PBR regime.

7. Conclusion

Public utility commissions are increasingly moving towards performance based regulation in a deregulated environment in order to ensure an acceptable level of service reliability to customers. In this endeavor, PUCs are utilizing utility historic reliability performance as a major element in establishing specified service reliability performance guidelines. The historic reliability information compiled by distribution utilities provides a measure of past system performance. The past system performance is extremely useful in predicting future system risks and the relevant remedial actions required to achieve specified service reliability levels. This paper has illustrated the applications of historic utility service reliability performance to establish an appropriate reward/penalty structure in the emerging performance based regulation of distribution companies. This RPS also includes incentives determined by the public utility commissions in regard to future desired performance.

The system reliability characteristics of individual utilities differ due to diversities in service areas, load densities, circuit ratios, system topologies, weather environments, and service standards. Urban systems usually have short supply feeders, underground circuits and alternate power supplies, while rural systems typically have long supply feeders, overhead circuits, and dedicated power supplies and are subject to varied weather conditions. The historic reliability performance data for two different utility system examples presented in Tables I and II demonstrate the effects of system diversities. It is therefore extremely important for regulatory commissions to include individual utility system characteristics in setting a reward/penalty structure. Finally, the approach of using reliability index probability distributions together with the average annual index values is an important tool in eliminating the impact of annual index variations and establishing appropriate reward/penalty structures in a PBR plan.

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