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Service and Voltage Sag Study of Humid and Dry Weather Utilities

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ABSTRAK

Kertas ini membandingkan masalah lendut voltan yang teruk dua utiliti yang biasa terdapat beroperasi di persekitaran yang lembap dan panas kering. Berdasarkan kepada data kualiti kuasa dan analisisnya, ia cuba untuk membandingkan kualiti perkhidmatan kepada pelanggan rupa bumi cuaca lembab dan kering. Untuk menyempurnakan kajian ini Tenaga Nasional Berhad (TNB) Malaysia dan Pihak Berkuasa Pembangunan Kuasa dan Air Pakistan(WAPDA) telah dipilih. Sejarah kegagalan sistem pengagihan elektrik kedua-dua utiliti, membawa kepada kepincangan tugas atau tiada diskriminasi operasi komputer mengawal proses industri, geganti pelindung dan penyentuh elektromagnetik jenis AC, dengan demikian menguatkuasakan penutupan pengguna akhir sedar kualiti, telah dianalisis untuk memperkukuhkan keagresifan lendut voltan di kedua-dua kawasan. Indeks keboleharapan kualiti kuasa telah dikira untuk mengukur persembahan sistem operasi. Kajian tersebut difokuskan untuk merumuskan algoritma bagi menganggar kemungkinan gangguan di luar pengurusan industri beroperasi dalam persekitaran lembap dan panas kering. Pengaruh kualiti kuasa yang rendah ke atas industri seperti perlindungan utiliti dan peralatan kawalan telah dianggarkan daripada data berkaitan beberapa tahun lalu. Kajian keboleharapan kualiti kuasa membuat kesimpulan bahawa lebih tinggi tahap penebatan untuk persekitaran lembap dan cuaca panas rata. Semasa perbandingan ini projek kajian kualiti kuasa ke atas sebab lendut voltan dan indeks keboleharapan bocoran keadaan stabil, didapati bahawa 77% lendut voltan adalah disebabkan oleh kesilapan litar pintas pada rangkaian, 11% disebabkan kesilapan antara kemudahan tetapi tiada sebab boleh dikaitkan dengan baki 14% lendut voltan yang terhasil dalam belantikan pemacu, kipas alir bebas, pemampat PLC, pam amonia, penunu dan pengawal proses. Indeks keboleharapan utiliti lembab didapati secara relatifnya lebih lemah daripada yang setara dengannya. Kemungkinan lendut voltan yang teruk di persekitaran lembab didapati lebih banyak daripada utiliti rupa bumi cuaca panas kering.

ABSTRACT

This paper compares the voltage sag severity problems of two typical utilities operating in humid and dry hot environments. Based on power quality data and its analysis, it has been attempted to compare the quality of services to the customers of humid and dry weather terrains. To accomplish this study Tenaga Nasional Berhad (TNB) Malaysia and Water and Power Development Authority (WAPDA) Pakistan were chosen. Electrical distribution system fault histories of two utilities, leading to malfunctioning or indiscriminate operation of industrial process controlling computers, protective relays and AC type electromagnetic contactors thereby imposing costly shutdowns to quality conscious end users, were analyzed to establish the severity of voltage sag aggressiveness in both areas. Power quality reliability indices were calculated to measure the operational system performance. The study has been focused to formulate algorithm for estimating probability of nuisance trip outs in industrial organizations operating in humid and hot dry environments. Influence of poor power quality on industrial as well as utility protection and control equipment has been estimated from the field data spread over a few years. This power quality reliability study concludes that there are higher insulation levels for humid environments than the plain hot weathers. During this comparative power quality study project on the causes of voltage sags and steady state outages reliability indices, it was found that some 77% voltage sags were caused by short circuit faults on utility network, 11% due to inter facility faults but no cause could be assigned to remaining 14% voltage sags resulting in tripping of drives, draft fans, compressors PLCs, ammonia pumps, incinerators and process controllers. The reliability indices of humid utilities were found relatively poorer than its counterpart. The probability of severe voltage sags in humid environments was found to be much more than the dry hot weather terrain utilities.

Keywords: Voltage sags, SAIDI, SAIFI, CAIFI and power quality

INTRODUCTION

Power quality (PQ) problems are unwanted guests to both the utility and the facility. Power system disturbances do result in revenue loss to utility and costly downtime in industry. In industrialized countries power quality is a burning issue. Customers blame utilities for supplying unreliable power and utilities accuse customers for injecting electrical pollution into transmission and distribution systems. US color books (IEEE series) have established some criteria by suggesting limits on utilities as well as facilities. A utility can improve the quality of its power by the use of active power line conditioners, storage devices, filters and periodic routine maintenance of the protective relays. Previous studies have reported some 36 out of 49 trippings are due to simple causes aggravated by problems related to the protective relaying system (Tamronglak, S. and S.H. Horowitz *et al.* 1996). These problems are often caused by bad wiring of control circuits, AC/DC grounding, moisture in airtight pockets such as monostats, water ingress on transformer top mounted devices, undetected inbuilt problems and improper settings on relays. Power quality problems such as voltage sags, surges, impulses, swells, notches, flickers and harmonics may cause infrequent mal-operation of drives process controllers, computers, magnetic contactors, PLCs, industrial lights and compressor motors. Compressors and PLCs are usually the heart of a continuous process, which upon tripping causes a shutdown of the plant. Critical equipment are mostly affected by voltage sags and switching surges. There is a great deal of jargon used to describe momentary disturbances. Several authors (Key 1978; Koval and

Leonard 1990; Koval 1990) and IEEE color books have attempted to standardize momentary disturbances but still others have their own point of view. The anatomy of generally referred power system disturbances is defined in several publications (WAPDA GUJRANWALA 1996; Conrad and Little 1991; Dugg and Ray 1996). Voltage sag was poorly understood in the past but now there is a complete consensus that the voltage sags are caused by short-circuit faults on the utility transmission or distribution network and are the major source of industrial sensitive equipment disruptions.

Power Quality Study

PQ study mainly consists of determining momentary variation of voltage, current and frequency relative to their steady state values. If the sensitive equipment works as desired, then there is no need for conducting power quality studies. Otherwise it becomes necessary to identify the causes to opt for economically justified ride-through devices. It is well known that the PQ sensitive devices are themselves often the cause of inducting surges in the distribution system. Electrical control and protection equipment such as PLCs, magnetic contactors, AC/DC drives, relays and communication devices are usually sensitive to many types of power system disturbances. The electrical system susceptibility is best illustrated by computer business equipment manufacturers associations (CBEMA) susceptibility envelope described elsewhere (Tamronglak and Horowitz 1996; Key 1996; Koval and Leonard 1990; Koval, 1990; WAPDA GUJRANWALA 1996). Common types of disturbance recorders may include TR-16 40 (Rochester), 626-PA (Dragnets), AMX-1600 digital oscillograph (Kinkei system corp.), YR-8 (Yoshio Electric Co. Ltd.) and power scope (BMI model 4800). As part of this study, power and service quality data were collected from WAPDA and TNB. The threshold pick-ups and sensitivities of the various types of equipment found in this PQ study are shown in Table 1 (Conrad and Little 1991). These settings were found on sensitive industrial customer relays, which were suffering from voltage sags problems.

TABLE 1
Threshold pickups and dropouts of voltage sag sensitive equipment

Equipment	Pick up		Drop out	
	Sag (%)	Duration (cycles)	Sag (%)	Duration (cycles)
AC Contactors	20	4	>20	4
DC Contactors	20	8	>20	4-8
Industrial drives	5-15	1-5	>5-15	1-5
PLCs	15-20	instant	>15-20	instant
Process Computers	10	5-10	>10	5-10
Mercury Lamps	50	2	>50	2
High Discharge lamps	10-15	1	>10-15	1

It is well known that if both leading edges of voltage and current are positive or negative going then the impulse is likely to have originated from utility side. However, if voltage polarity is positive going and current is negative going or vice versa then the source of disturbance may be somewhere on the load side (Price 1993). Similarly, if the voltage sag continuously goes down on an analyzer in industry then fault lies downstream. However, if the voltage sag recovers after a few cycles back to the normal, then the source of voltage sag is somewhere upstream (Reason 1992). If the analyzer record is a voltage sag followed by a continuously decaying DC voltage, then it is nothing except discharge of capacitors after tripping of the controlling circuit breaker. There may be an interesting record of continuously decreasing voltage and frequency which are often caused by motor's generator action during voltage sags or sudden disruption of a process involving high inertia loads (Conrad and Little 1991).

UTILITIES DATA ANALYSIS

To estimate utility performance and its impact on industrial downtime, the SS & T Division WAPDA Gujranwala, a model town Subdivision Gujranwala and the Ghakhar Subdivision Ghakhar, under AEB, WAPDA Gujranwala were chosen as random samples to determine overall performance of WAPDA. A similar PQ study was focused on TNB sub transmission and distribution network feeding to Selangor, which is the most developed state of Malaysia. Utilities tripping data analysis was conducted in comparison to industrial electrical failure history. The findings obtained by data analysis of WAPDA and TNB tripping histograms has shown that short circuit faults on the lines cause voltage sags that result in tripping of most of the industrial equipment and often the utility's own protection and control devices. A reasonable number of indiscriminate trippings is recorded by WAPDA and TNB. Both TNB and WAPDA need to give attention to high numbers of indiscriminate trippings on their networks. The main cause of indiscriminate tripping on TNB network may be the highest isokeraunic level and humidity leading to insulator flashover. The data for Malaysian thunderstorm days (TD)/year) as compared to some international cities is shown in Table 2.

TABLE 2
Thunderstorms Days/Yr Data

Name of City	TD/Yr
Tokyo (Japan)	20
Subang (Malaysia)	330
Lahore (Pakistan)	330
Miami (USA)	100
Penang (Malaysia)	290

The causes of voltage sags may vary but the average number of voltage sags caused by faults on utility networks in Pakistan and TNB Malaysia is much more than the practices adopted in standard international utilities. The frequency of faults in TNB is less than WAPDA but the number of unidentified trippings is much higher. Some of the international utilities have reported 80% of voltage sags caused by lightning and the others declare the number of voltage sags to be directly proportional to short circuit faults on utility or facility distribution networks. Thus the voltage sags are considered to originate from short circuit faults. Therefore, to minimize voltage sags on systems the utilities need to increase maintenance to reduce frequency of faults on their networks.

Voltage sag severity may be represented by several methods. 3-D plot of TNB voltage dip magnitudes, duration and frequency of occurrence are shown in *Fig.1.* TNB and its customers record voltage sag profiles but WAPDA and its customers normally do not record them except for a few cases. We estimated WAPDA sag durations from the controlling circuit breakers and magnitudes by making reactance diagrams of the 11 kV feeders. The sag magnitudes were found similar to the standard published and generally recorded values. Based on field experience and present research on TNB and WAPDA Gujranwala, it is concluded that the frequency of severe voltage sags in radial systems are far more than meshed networks. Average number of sags/yr in WAPDA is more than TNB but less than many South Eastern utilities operating in similar environmental conditions.

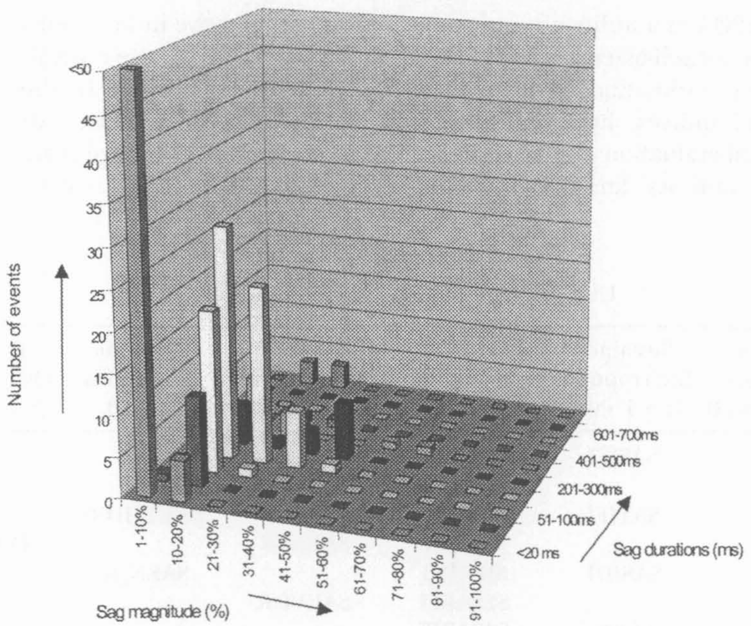

Fig. 1. A typical TNB 3D plot of voltage sags durations, magnitudes and frequency of occurrence

SERVICE QUALITY CRITERIA

Competitiveness of a utility performance depends upon the quality of service provided to its customers. If the customers are satisfied with the supply services then there is no more question about it, otherwise, the utility performance may be estimated from its statistical service in respect of outages, sustained interruptions, momentary interruptions, harmonics and transient indices. Long ago, the utilities progress could only be weighted in terms of its outages based indices such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), customer average interruption frequency index (CAIFI) and average system availability index (ASAI) [7, 10, 11]. The customers were supposed to be affected only during outages due to simple loads. Development in semiconductor VLSI technology has resulted in quite sensitive devices that can easily be interrupted by surges and transients. Thus the above concept of indices was substantially modified to incorporate the effects of sustained interruptions on distribution systems. Most of the utilities still use above five types of indices to evaluate their performance but more efficient utilities have started to measure their competitiveness in terms of momentary and transient indices in view of sensitive equipment reported to be affected even by transients. This study is limited to calculation of outages (>5 min) based indices, SAIDI, SAIFI, CAIFI, CAIDI and ASAI, but the details of other indices are shown in Table III for information and further pursuance of work both in WAPDA and TNB.

WAPDA as a utility not only must calculate the above indices but should also prepare for self-assessment regarding quality of services to the critical customers. A perfect estimation of utility service quality is only possible by the above six types of indices, however, an average guess may be obtained only by the statistical evaluation of interruptions/outages occurring for more than 5 minutes. To the authors' knowledge, both TNB and WAPDA do not calculate all the

TABLE 3

Utility service quality reliability indices [10-14]

System Outages ($t \geq 5$ min)	Sustained Interruptions ($t > 1$ min)	Momentary Interruptions ($t < 1$ min)	Voltage Fluctuations (Steady state)	Harmonic Distortions (THD)	Transient Over voltages ($t <$ few ms)
SAIDI	SASIFI	SARFI			
		SIARFI	SAEVUR		
SAIFI	SATIFI	SMARFI		SAETHDRI	
		STARFI	SAENSR		SATMORI
CAIFI	SASIDI	SIPARFI		SAEN$_h$RI	
		S2PARFI	SAEVDR		
CAIDI	ASIDI	S3PARFI			
		ARDI			
ASAI					

above indices. However, TNB calculates SAIFI, SAIDI and CAIDI indices but WAPDA is still planning to start calculation of above indices in the near future. In the present study, the authors have attempted to calculate two of the above indices to compare it with TNB data.

UTILITIES SERVICES INDICES

Above indices were calculated for WAPDA on the basis of data of five 11 kV feeders of model town Subdivision feeding to 7956 domestic, 3256 commercial and 1230 industrial consumers. This choice shows a reasonably good admixture of sensitive industrial and commercial users. Due to time constraint and lack of desired data, only SAIDI and SAIFI indices could be calculated. To estimate the average value of SAIDI it was assumed that HV outages from grid station affect all the 11 kV customers on all feeders emanating from the grid. The 11 kV feeder faults just cause outages to the concerned customers without disturbing parallel feeder customers. Similarly for calculating SAIFI it was assumed that faults on 11 kV feeders not only disrupt customers connected to these feeders but also some 2% of the nearby customers on parallel feeders. Computation of these indices is based on the assumption that all the HV and 11 kV outages are cleared within 5 and 2 hours respectively. In view of limited information these indices may be considered approximate and rough representations where no such data is available.

Overall WAPDA performance may not be based on this study as the data was incomplete and the authors chose the worst area cases. The service quality of utility can also be measured in terms of its momentary and steady state outages on transmission and distribution systems. WAPDA uses the radial system and its performance comparison with TNB and other international utilities is shown in Table 5. Similarly, the causes of sags of different utilities are shown in Table 5.

The outages per year data are accurate but momentary interruptions per year data are approximate in light of the operator's ignorance to record it. Although the actual data supplied by the subdivision was compared to records of the concerned Shaheenabad Grid Station, still the general practice of utilities to hide or conceal their actual fault figures, for better impression, cannot be ignored during analysis. Further, to probe a more generalized

TABLE 4
Average SAIDI and SAIFI indices of WAPDA and TNB as compared to standard international most efficient utilities

Utility	SAIDI (Hrs)	SAIFI
WAPDA (Dry)	1271@	11.68@
TNB (Humid)	642	3.98 - 4.28
Ideal Utility	1.0 - 1.5	1.0

@ These values correspond to urban areas of District Gujranwala.

TABLE 5
Percentage contribution of causes of voltage sags in WAPDA and TNB.

Causes (Types)	WAPDA (Pakistan)	TNB (Malaysia)
Insulator flashover	31%	8%
Indiscriminate	32%	**43%**
External touches	**14%**	9%
Equipment failure	23%	40%

estimate of supply service quality it was decided to focus on distribution subdivision at WAPDA Ghakhar under Wazirabad Division. This Subdivision supplies electricity through six 11 kV feeders to some 15395 consumers.

These six feeders emanate from the 220/132/11 kV Grid station Ghakhar along with 11 other parallel feeders falling in jurisdiction of the other Subdivisions. All the 17 feeders supply electricity at 11 kV voltage level to some 38488 customers. The indices were calculated using the above-mentioned assumptions. Data collection showed those 2558 faults (resulting in tripping of circuit breakers) occurred on 17 radial 11 kV feeders in 1996. The measured data indicates 2364 faults on 11 kV parallel feeders and 194 on the WAPDA 220/132/66 kV transmission lines. These faults resulted in 2558 voltage sags on the 11 kV feeders. It is, therefore, estimated that (including severe and mild sags) some 2558 sags occurred for each of the 38488 consumers fed from 17 feeders. This is due to parallel connection of 17 feeders from the same substation. The traditional utility service quality indices were calculated on individual feeders and subdivision basis.

CONCLUSIONS

To minimize voltage sag problems WAPDA and TNB may adopt strategies including but not limited to reduction of number of faults, improvement in maintenance and repair, going for higher voltage transmission, increment of local VAR support during faults, increment of generation and spinning reserve, installation of shield wire, replacement of deteriorated cables and choice of better insulators on over head EHV lines. Based on the results of this power and service quality comparative case study, it can be concluded that the number of faults on utility transmission and distribution network is directly proportional to the voltage sags to the customers. The overhead transmission and distribution network appears to behave as more exposed to power quality issues than the underground/concealed systems. Higher number of indiscriminate trippings is alarming. WAPDA and TNB service quality indices reflect that they have not any self-imposed or adopted recent international practice. As TNB computes at least three indices so its underground trend is more competitive than WAPDA. This may partly be attributed to utility priorities and monopoly. Power and service quality statistics are almost similar in most of the developing countries, but as international utilities, the WAPDA and TNB may consider adopting recent international practices to minimize the momentary interruptions to their consumers.

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