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Evaluation OfFeeders Reliability By Using Events Recordand Power Performance Indexes

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Abstract : *There is a positive relationship between the change of voltage parameters, power interruption and power supply reliability. It is an innovative thinking to judge the reliability of power supply by the number and duration of voltage events. Based on the basis of parameter measurement and statistics of power quality that develops an innovation method of power performance duration index evaluate reliability of feeders. The reliability can be evaluated according to the magnitude of the index which in larger mean the greater occurred event rate and the less the reliability. On the contrary, index in smaller mean smaller the event rate and the better the reliability. The ideal power supply event rate is zero an on the relatively; the ideal power supply event duration index is also zero. Innovation defines the power performance indexes which cover the two indexes as the interruption performance index and the events performance index. (1) Uses the voltage interruption data to derive the average interruption duration index (AIDI). And (2) uses the voltage swell and voltage dip data to derive the average event duration index (AEDI). A new method was proposed to evaluate the reliability of the feeder by AIDI and AEDI. The derivation of AIDI and AEDI for two different types of feeders which including underground and overhead feeders possess the bad power quality that can be improved. However, form the view of measurement that the overhead feeder has better power quality and better reliability.*

Keywords -*Power quality, Reliability, Events Record, Power Performance Indexes*

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I. INTRODUCTION

The International of Electrical and Electronics Engineers Institute defines power quality as the relative lack of power systems disturbances. The ideal power supply waveform no matter how the in any case and the voltage level is within the allowable range, the frequency range is within the allowable range, and the continuous power supply cannot be power down except the natural disasters and human errors. Power quality ranges include surges, voltage swells, voltage sags, noises, power interruptions, harmonics, voltage flickers, over voltage, under voltage, low voltage, and imbalance of three phase and frequency variations and so on. In general, the power quality problems of industrial power distribution systems is more concerned about surges, voltage swells, voltage sags and power interruptions. The high-tech industry is more concerned about voltage sags and harmonics. And Steel plants are aim at with voltage interruptions, harmonics and flicker.

From the viewpoint of power quality that (1) there are the following articles to assess and measure the power quality :integrating renewable energy with power quality discussion[1], Exploring the power quality of smart grids with guest editorial special Issue[2], using model sequential method monitoring to distinguish the classification of power quality disturbances[3],use trend fluctuation analysis to diagnose power quality events[4],electrical device with intelligent sensor and communication network power quality monitoring[5] and application of Fourier series transform to discriminate power quality disturbance[6]. (2).And there are ways to improve power quality as following:apply the double-tree complex and small wavelet transform control algorithm to improve the power quality of the power distribution system [7], by Using voltage restorer with energy optimization of double P-Q theory to dynamically improve power quality of distribution system [8] and grid-connected symmetrical cascaded multilevel converter for improving power quality [9].

From the perspective of reliability which are still many discussions about engineering: (1) The reliability of the literature is as follows:considering cold load pickup events to assess reliability of distribution systems[10],reliability promotion of multi-group group identity measurement correction[11], reliability assessment of Jizhou Island wind turbine with energy storage system[12], derivation of reliability contribution function of power generation system for wind turbine integrated battery energy storage system[13] and discussion on durability and reliability of electric vehicle battery using bidirectional charging impact effect of power grid. (2).The method of improving reliability is as follows: improving the reliability of distribution network based on micro-grid topology planning[14], multi-energy power and natural gas interconnection optimization plan[15,16] and reliability optimization of automated distribution network based on interruption cost model.

The viewpoint of using the power efficiency method to evaluate reliability is as follows:combination with renewable energy and passive buildings to evaluation of distribution by energy performance index [17] and smart grid security assessment based on new chaotic performance indexes [18].

In this paper, based on the basis of parameter measurement by voltage events record and statistics of power quality that develops an innovation method of power performance duration index evaluate reliability of feeders. Innovation defines the power performance index which covers the two indexes as the interruption performance index and the events performance index to evaluate the feeder reliability.

II. DEFINITION AND DISTORTION OF POWER QUALITY PARAMETERS

2.1 Definition

IEEE-1159 definition and classification of power system interference phenomena such as the table 1 that include all of the power quality parameter in normal and abnormal which are occur in power systems and distribution system to evaluated the power quality of supply-side and demand-side. Especial the power interruption is the significant effect the power quality.

Table1. Definition and classification of power system interference phenomena

NO	classification			Typical spectrum content	Typical duration	Typical voltage magnitude
1	Transient	Impulse	Nanosecond level	Rise Time 5ns	< 50ns	-
			Microsecond level	Rise Time 1us	50ns-1ms	-
			Millisecond level	Rise Time 0.1ms	>1ms	-
		Oscillation	Low frequency	< 5kHz	0.3~50ms	0~4 p.u.
			Intermediate frequency	5~500kHz	20us	0~8 p.u.
			high frequency	0.5~5MHz	5us	0~4 p.u.
2	Short time voltage variation	Instantaneous	Voltage swell	-	0.5~30 cycles	0.1~0.9 p.u.
			Voltage sag	-	0.5~30 cycles	1.1~1.8 p.u.
		Moment	Power interruption	-	0.5 cycles~3s	< 0.1 p.u.
			Voltage sag	-	30 cycles ~3s	0.1~0.9 p.u.
			Voltage swell	-	30cycles 3s	1.1~1.4 p.u.
		Temporarily	Power interruption	-	3s ~1min	< 0.1 p.u.
			Voltage sag	-	3s ~1min	0.1~0.9 p.u.
			Voltage swell	-	3s ~1min	1.1~1.2 p.u.
3	Long time voltage variation	Continuous voltage interruption	-	-	>1 min.	0.0 p.u.
		Under voltage	-	-	>1 min.	0.8~0.9 p.u.
		Overvoltage	-	-	>1 min.	1.1~1.2 p.u.
4	Voltage imbalance		-	-	-	0.3~2%
5	Waveform distortion	DC component	-	-	-	0~0.1%
		Harmonic	0~100 order	-	Steady state	0~20%
		Inter-harmonics	0~6kHz	-		-
		Voltage dent		-	-	0~2%
		Noise	Broadband	-	-	0~1%
6	Voltage fluctuation	-	<25 Hz	-	Intermittent	0.1~7%
7	Power frequency changing	-	-	-	< 10 s	-

2.2 Voltage Distortion

2.2.1 Voltage swells

In figure 1 show a voltage swell waveform diagram for AC 220V which the voltage of the electrical angle in 1080~2520 is greater than the root mean square (RMS) value to the nominal voltage. A voltage swells may cause damage or burnout of the instrument or electronic equipment because the voltage value exceeds the rating of the electronic device or instrument. Short-term voltage surges are usually caused by system failures such as single-phase ground faults and non-faults also have a brief voltage rise phenomenon such as large-scale load shedding or capacitor bank switching in can also cause the short-term voltage swells. The RMS voltage of the long-term voltage swell is more than 110% of the normal voltage and the duration of more than 1 minute often occurs in the insufficient power controller device capacity installed, the incorrect transformer tap switching and the large load switching on or off. The improvement method is that the shedding of the large load equipment in the plant should be matched with the relevant power factor to improve the switching action on the device to avoid the overvoltage phenomenon generated when the heavy load is cut off.

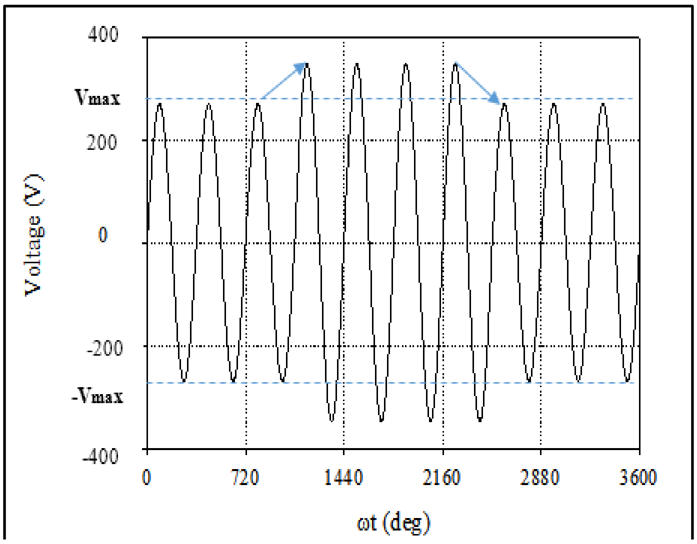


Fig.1. Voltage swell waveform diagram

2.2.2 Voltage sag

In figure 2, it is a voltage sag waveform diagram which voltage within 1080~2520 electrical angle is smaller than the voltage RMS value of the nominal voltage and between 0.1 and 0.9 p.u.. In general, voltage sags is usually caused by a large motor start, overload, short circuit or mismatched line diameters and delivery currents. The distance between the measurement position and the fault point is closely related to the magnitude of the voltage sag. The closer the fault position is the larger affected the voltage sag. On the contrary, the farther away from the fault position will let the voltage sag is less affected.

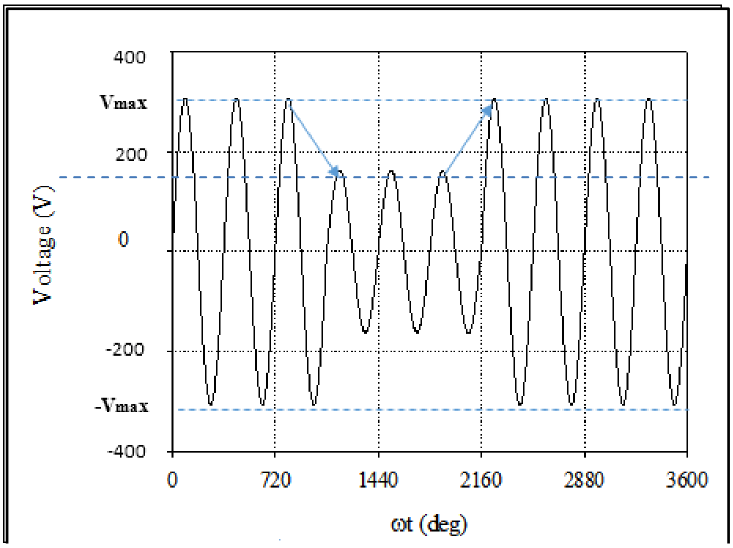


Fig.2. Voltage sag waveform diagram

2.2.3 Power interruption

Figure 3 shows the voltage interrupt waveform which within 1080~~2520 electrical angle and the voltage RMS is became to close or equal to zero and This voltage cannot drive any electrical equipment that made in supply-side is no power to supply and in demand-side is outage. In general, power interruption is mainly caused by equipment failure, power system protection relaying mistake operation or power dispatching leading to long-term power interruption. And natural disasters such as lightning strikes, storms and traffic accidents are also one of the causes of power outages.

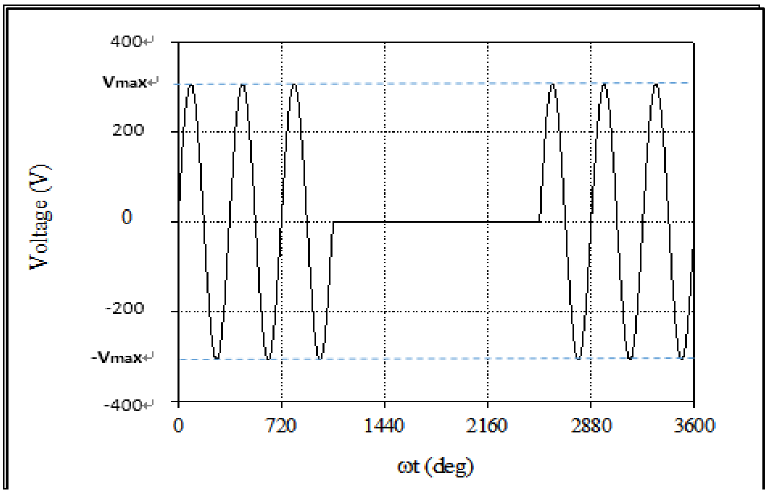
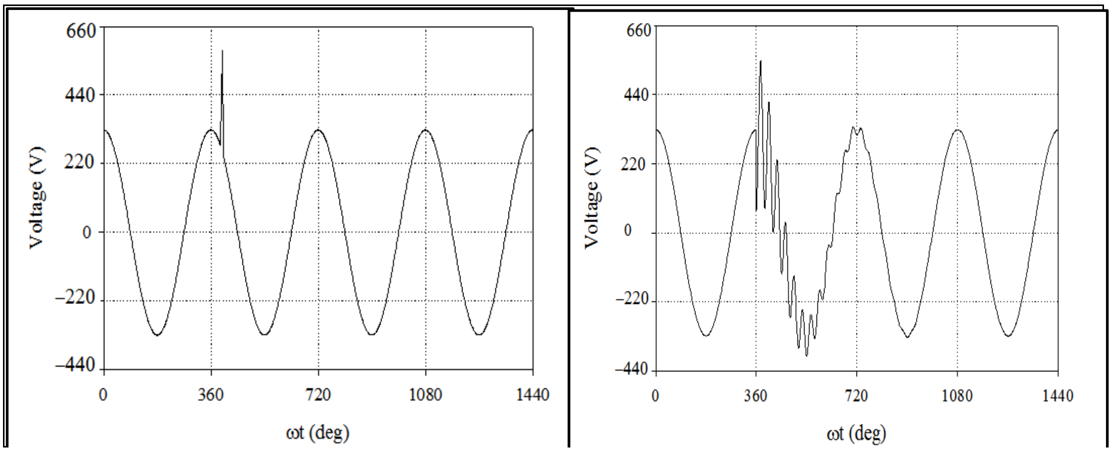


Fig.3. Power interruption waveform diagram

2.2.4 Waveform transient of voltage

In the transient phenomenon power quality which waveform distortion, voltage transient, power interruption, voltage dip and voltage swell are one of all part of the power transient signal. Different oscillation transients can be divided into high frequency, intermediate frequency and low frequency oscillation transients by the main spectral components, duration and amplitude. Broadly speaking, the transient state can be divided into two types: impulse transient and oscillatory transient. As shown in Fig. 4(A), 4(B) are pulsed transient and sinusoidal oscillation transients which are harmful to the electrical appliances at the demand-side regardless of whether the voltage transient is positive or negative.



(A) Impulse transient waveform (B)Sinusoidal oscillation transients waveform

Fig.4. Voltage transient waveform

2.2.5 Voltage imbalance

Voltage imbalance means that the magnitude of the three-phase voltage is not equal or the phase difference between any two voltages is not 120 degrees, or both situations occur simultaneously. Such as the figure 5 is the voltage imbalance diagram of three-phase. Voltage imbalance is mainly caused by unbalanced loads, especially large single-phase loads such as electric railways. In addition, if the transmission line is not replaced position and transformer of V-V connection, etc. that will let the impedance of the three-phase circuit will be asymmetrical and indirectly will cause the imbalance of the three-phase voltage.

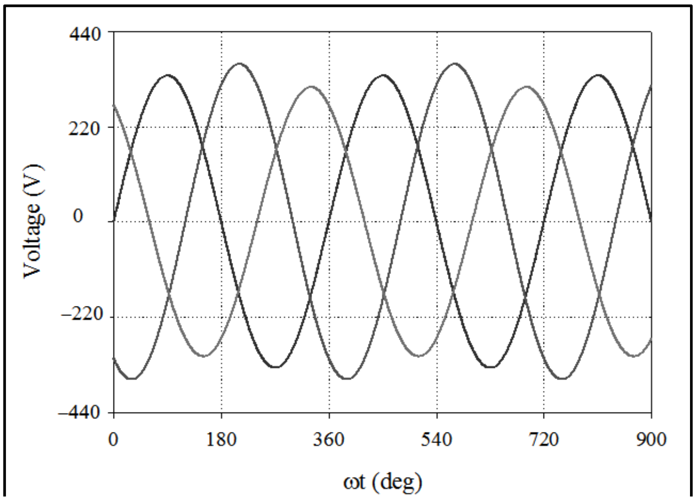


Fig.5.The voltage imbalance diagram of three phase

2.2.6 Frequency variation

The system frequency often represents the balance between the supply and demand of effective power so that the increase or decrease of the load often causes the system frequency to rise or fall. Therefore, the system frequency also reflects the balance between the power supply and the load such as the figure 6 is a waveform diagram of voltage frequency variation. Usually only when the transmission system fails such as for example the load of the entire city suddenly cuts off from the power system or a large power plant is suddenly cut off that will made the system frequency change will exceed the scope of normal operation. The situation in which the frequency fluctuates greatly generally occurs in a single system powered by a single generator that the governor of the generator generally cannot react to the load change immediately and thus made the frequency fluctuates.

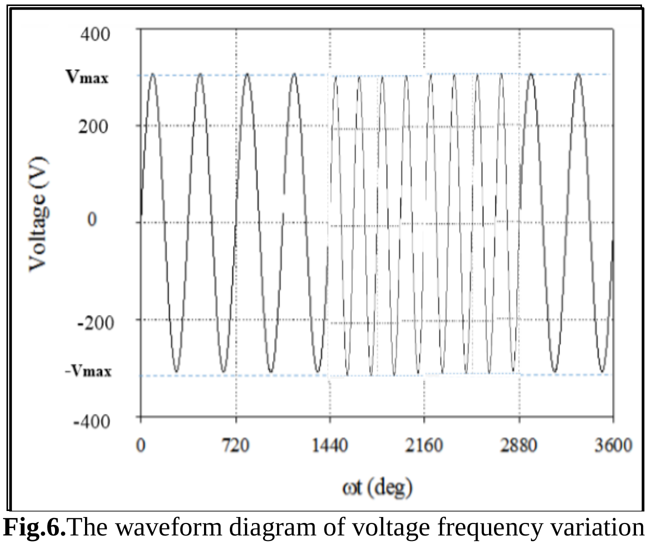


Fig.6. The waveform diagram of voltage frequency variation

III. ABNORMAL POWER QUALITY PARAMETERS MEASUREMENTS AND COLLECTION

3.1 Function of Voltage Accident Recorder

The voltage event recorder FLUCK VR101 can measure problems such as surge, voltage swell, voltage sag, power interruption, over voltage, low voltage, under voltage, three-phase voltage imbalance and frequency variation according to the set up number voltage event recorder and connection. Figure 7 shows the application and appearance of the voltage event recorder FLUCK VR101. It has a common opinion that is must be set in low voltage side such as voltage level with 220V or 110 V.

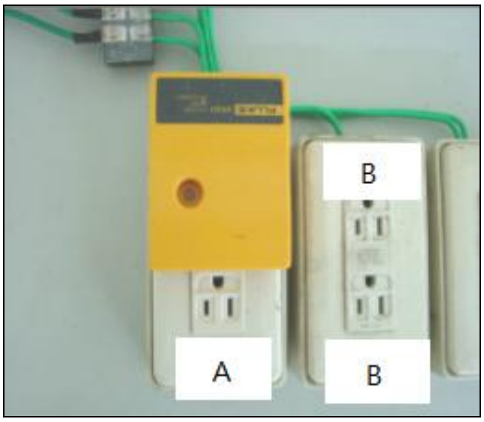


Fig.7. The application and appearance of voltage event recorder

3.2 Measuring connection and object

3.2.1 Device Connection

It is selected two different type feeders to study which both type are the overhead system of 11.4 kV and underground system of 22.8kV, respectively. The voltage event recorder is directly installed on the low voltage side of the high voltage feeders 11.4kV or 22.8kV which are directly stepped down to the low voltage of 110V via the step-down transformer do not installed on the downstream low-voltage side of the protection relaying system which it will detect error data of object feeder by the intermediate system affected. In view of connection that the voltage event recorder is similar to the voltage signal of the low voltage directly measured in parallel with the feeder and figure 8 is shown the device connection.

Fig.8. Event data link by optical interface cable between computer and VR101

3.2.2 Event data link

The VR101 is a starter system that includes a compact VR101 event recorder, an optical interface cable, and EventView™ software that turns your PC into a power quality reporting tool such as figure 10. Additional VR101 event recorders can be purchased individually, so you can monitor several voltage conditions at multiple locations at once. To set up a VR101 event recorder, just enter the event capture limit parameters on your PC and load them into the recorder. EventView™ software and the optical interface cable make it easy. Then plug the recorder into the outlet you need to test, and leave it—there's no need to leave a computer hooked up. The compact recorder stores any voltage event that goes outside your limits. The VR101 recorder can store up to as many as 4000 events and a flashing LED tells you when events have been captured. To get data out of the recorder, hook it back up to your computer. EventView™ software can download a complete history of the events that occurred while the recorder was plugged into the receptacle. The software lets you build a detailed report of sags, swells, transients, outages and frequency variations with time-stamps and durations.

3.3 Parameter setting of voltage event record

The voltage accident recorder uses a dedicated program to match the computer and communication to enter the internal settings and modify the parameters required for the desired voltage accident recorder.
The parameter items set in this research are below:

◦ Set the way and location to record and store data.

- Set the threshold value of live line for voltage swell, voltage sag and transient.
- Set the threshold value of neutral line for voltage swell, voltage sag and transient.
- Set the threshold value of frequency variation, recording maximum and minimum values.
- Set the instantaneous voltage and ground voltage display.

The data value obtained by the voltage event recorder is used to measure the event type, the event extreme value and duration time of each event that can be measured by the dedicated program of the voltage event recorder. Figure 9 is the parameter setting completion table of underground feeder and overhead feeders.

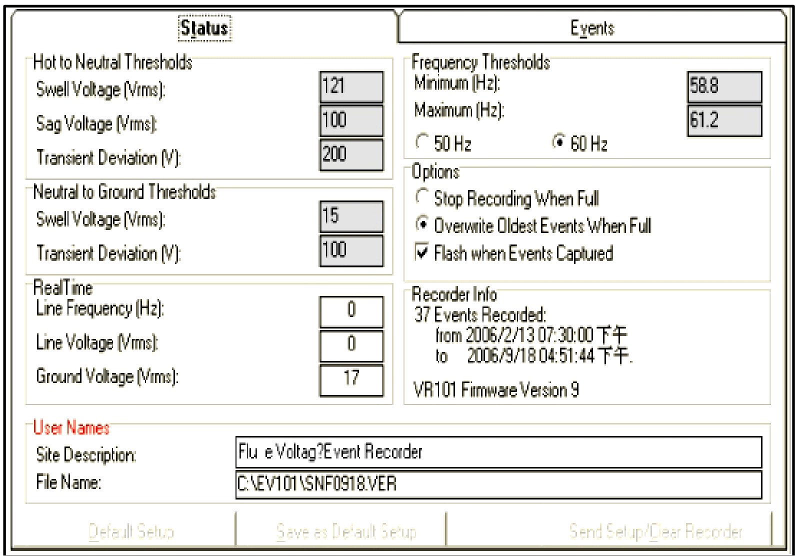


Fig.9. The parameter setting completion table

IV. VOLTAGE EVENTS STATISTICS

4.1 Partial voltage event record

There are two research objects, one is the underground feeder and the other is the overhead feeder and the sampling time interval of both is 12 weeks in synchronous. Table 2 is part of the information on the underground feeder of voltage events, and Table 3 is part of the information on the overhead feeder of voltage events. That include the typical voltage events such as H-N sag, N-G swell, H-N swell, outage, N-G transient, H-N swell and H-N transient.

Table2. Part of the information on the underground feeder of voltage events

No.	Event	extreme	End time/during/degree
1	H-N Sag	95 Vrms	12.8 seconds
2	N-G Swell	19 Vrms	54.1 seconds
3	Outage	0 Vrms	00:00:08
4	N-G Swell	19 Vrms	00:03:27
5	1 N-G Transient	+300 Vp	320°

Table3. Part of the information on the overhead feeder of voltage events

No.	Event	extreme	End time/during/degree
1	H-N Swell	123 Vrms	52.9 seconds
2	1 H-N Transient	+350 Vp	320°
3	Outage	0 Vrms	10:38:48
4	N-G Swell	140 Vrms	80.9 seconds
5	H-N Swell	129 Vrms	0.5 cycles

4.2 Statistics of data and graphical

During the measurement time which the voltage accident recorder can convert its data into the following three statistical charts. One is the statistics of the number of voltage events, the second is the live to neutral (H-N) and neutral to ground (N-G) voltage events statistics, and the last is the (H-N) and (N-G) voltage transient event extreme statistics.

4.2.1 Statistics the voltage swells voltage transient, voltage sag, frequency variation and power interruption times during the measurement period.

Table 4 is the voltage events during the measurement period of the underground feeder and figure 10 is the voltage events bar chart. It is has counted 36 voltage swells , 80 voltage transients, 15 voltage sags, 0 frequency changes and 35 voltage interruptions during the measurement period.

Table 5 is the voltage events during the measurement period of the overhead feeder and figure 11 is the voltage events bar chart. It is has counted 54 voltage swells , 168 voltage transients, 3 voltage sags, 0 frequency changes and 5 voltage interruptions during the measurement period.

Table4. Count voltage event times of underground feeder

Events / I^th week	Voltage swell	Voltage sag	Voltage transient	Frequency variation	Power interruptio n	Subtota l
1st week	1	0	0	0	1	2
2nd week	1	0	0	0	0	1
3rd week	1	0	0	0	0	1
4th week	0	0	1	0	0	1
5th week	0	0	0	0	1	1
6th week	0	0	0	0	0	0
7th week	3	7	24	0	9	43
8th week	2	5	32	0	12	51
9th week	0	0	1	0	3	4
10th week	0	0	18	0	6	24
11th week	27	0	3	0	3	33
12th week	1	3	1	0	0	5
Subtotal	36	15	80	0	35	166

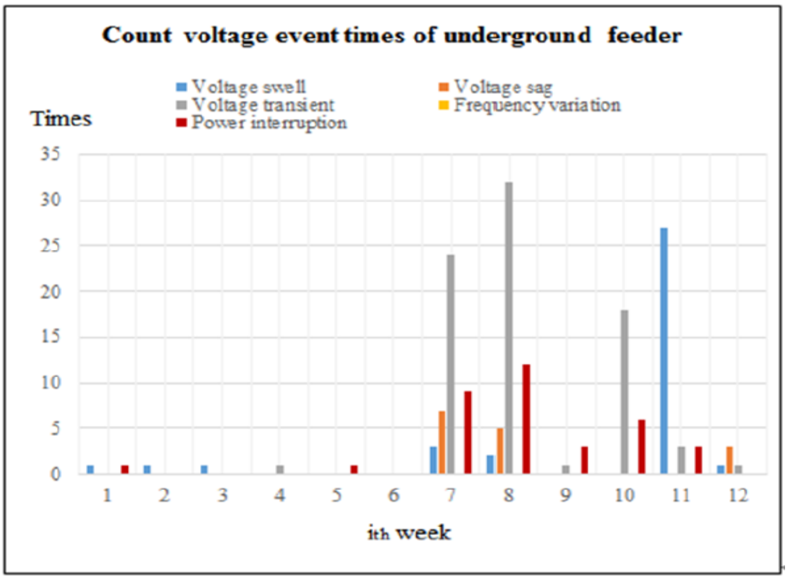


Fig.10.The voltage events bar chart of underground feeder

Table5. Voltage event times of overhead feeder

Events / i^th week	Voltage swell	Voltage sag	Voltage transient	Frequenc y variation	Power interruption	Subtotal
1st week	13	0	6	0	1	20
2nd week	9	1	20	0	0	30
3rdweek	17	0	14	0	0	31
4th week	7	0	8	0	0	15
5thweek	3	0	20	0	0	23
6thweek	2	0	25	0	0	27
7thweek	0	0	4	0	0	4
8thweek	0	0	7	0	0	7
9thweek	2	2	15	0	3	22
10thweek	0	0	8	0	0	8
11thweek	1	0	17	0	1	19
12thweek	0	0	24	0	0	24
Subtotal	54	3	168	0	5	230

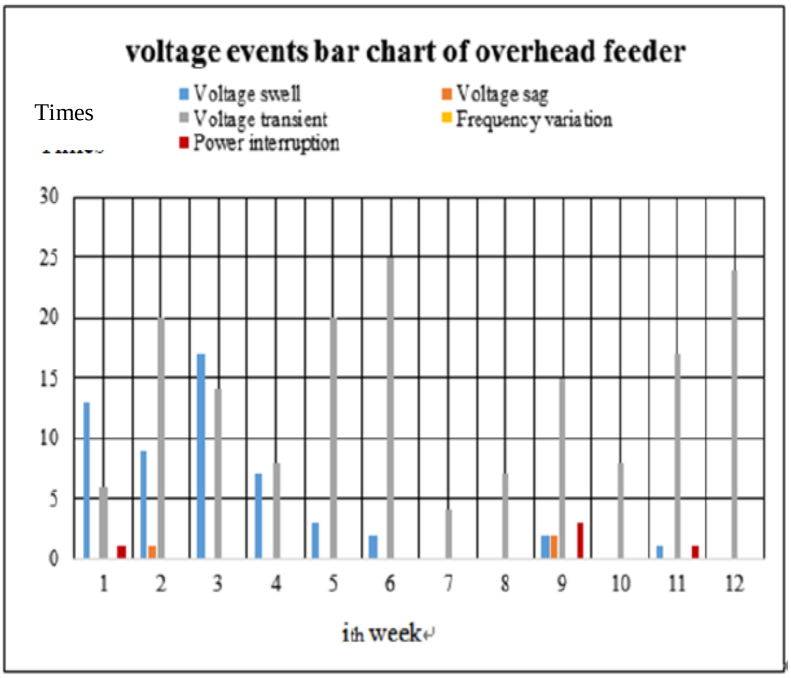


Fig.11. The voltage events bar chart of overhead feeder.

4.2.2 Observe the relationship between the duration of events and the magnitude of the voltage events that include two type, one live-neutral (H-N) and neutral-ground (N-G) extreme value and to plot the graphics.
Figure12 shows the coordinates of all events points of the underground feeder. By after the method of cluster analysis, it is divided into three sections, one for voltage swell event area as the section I, another for voltage sag event area as the section II and the other for power interruption event area as the section III. The similar is as the figure 13 for overhead feeder.
4.2.2 Observe the statistical diagram of the voltage transient event between the live-neutral (H-N) line or the neutral –ground (N-G) line.
Figure 14 shows the #31 event extracted by the voltage event recorder which measures at about 160 electrical degree in a one-cycle of 60 Hz finding the neutral-ground (N-G) transient voltage of underground feeder is as high as 160 Vp and this transient will have an adverse effect on the appliance.

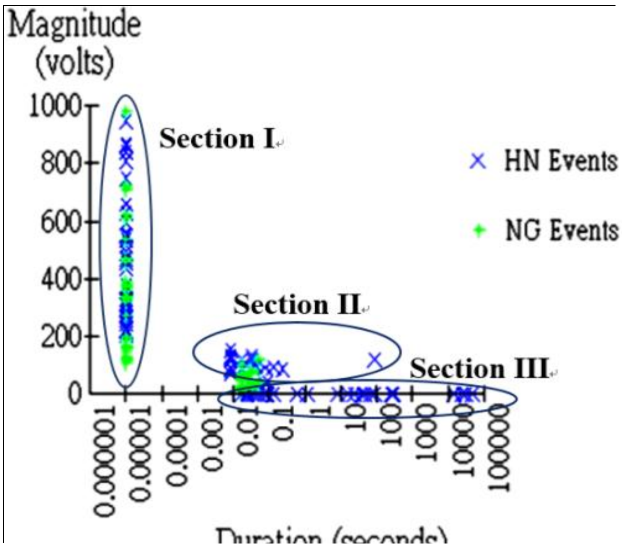


Fig.12.The coordinates of all events points of the underground feeder.

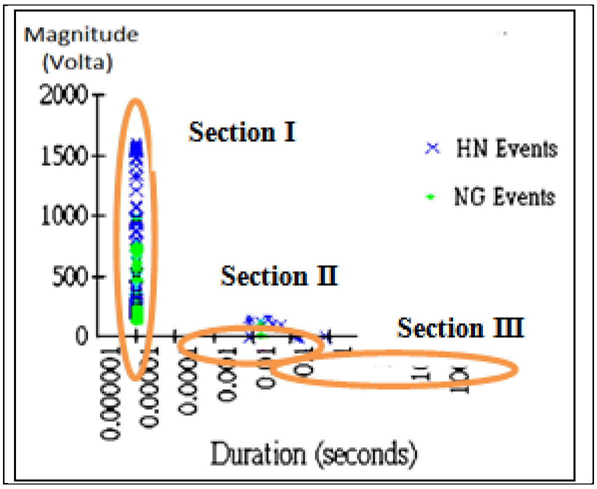


Fig.13.The coordinates of all events points of the overhead feeder

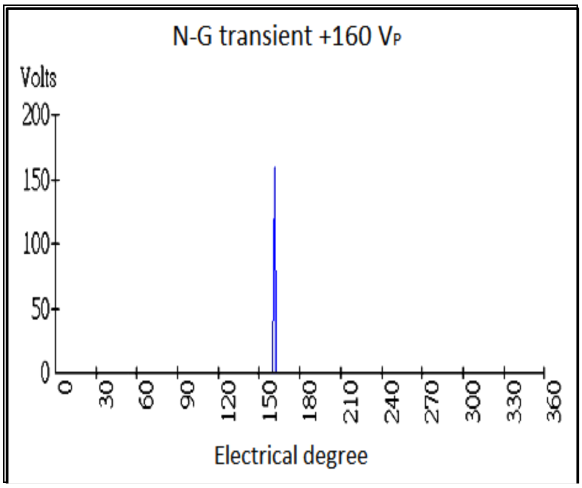


Fig.14. The N-G transient voltage event of underground feeder

V. POWER OUTAGE PERFORMANCE INDEX (POPI)

5.1 Power performance index definition

The performance index based on the event duration can be used to investigate the impact of the accident on the user. The performance indicators are divided into two indexes, one is the average interruption duration index (AIDI), and the other is the average event duration index (AEDI). The former is the indicator of the power outage coefficient, and the latter is the indicator of all accidents except power outages and transients. The performance indicators are defined as follows which can calculate and judge the reliability of the power provider.

5.1.1 Average interruption duration index (AIDI): Calculate the average time of power failure during the measurement time.

$$\mathrm{AIDI} = \sum_{i=1}^{N} \frac{\mathrm{IE_i}}{\mathrm{N}} \qquad (1)$$

Where

$\mathrm{IE_i}$: The ith interruption duration.

N: Interruption events total number.

5.1.2 Average event duration index (AEDI): Calculate the average time of each voltage event.

$$\mathrm{AEDI} = \sum_{i=1}^{M} \frac{\mathrm{VE_i}}{\mathrm{M}} \qquad (2)$$

Where

$\mathrm{VE_i}$: The ith voltage events duration.

M: Voltage events total number.

5.2 Outage performance index calculation

The data of interruption for both underground and overhead feeders of micro-grid is as shown tables 6. By statistical the measurement time of events duration and interruption number. As can be seen from the table, the AIDI of the underground feeder is 75.66 min. and the AIDI of the overhead feeder is 10.53 min. it is shown the AIDI of underground feeder is higher than the AIDI of both feeders. Figure 15 shows the measurement of the time and power failure of the two feeders.

Table6. Two different types of feeder interruption parameters and AIDI statistics

Feeder type	Power outages (times)	Total power outage time (minutes)	AIDI(minutes)
Underground feeder	35	2648.27	75.66
Overhead feeder	5	52.67	10.53
Subtotal/ average	40	2700.94	67.52

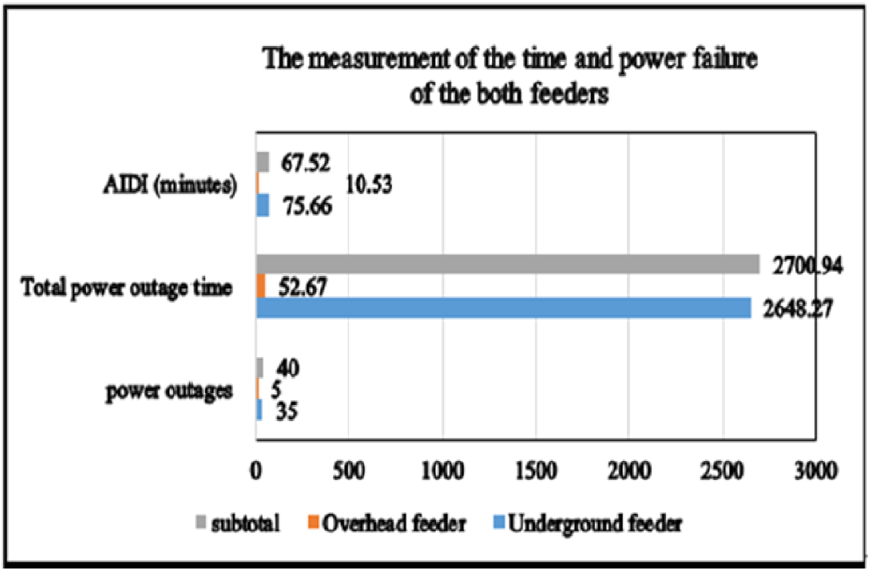


Fig.15.The measurement of the time and power failure of the both feeders

5.3 Event duration index calculation

The data of H-N and N-G voltage swells and H-N voltage sags in two different types of feeders are sorted out as shown in table 7.

Figure 16 shows the measurement of the time and voltage events of the two feeders.

Table7. Two different types of feeder voltage events and AEDI statistics

Feeder type	Data	Voltage swell		Voltage sag	Subtotal
		N-G	H-N	H-N	
Underground feeder	Number (times)	24	11	15	50
	Average time /AEDI (min.)	0.55	1.81	0.286	1.10
	Total time (min.)	17.65	23.48	14	50.13
Overhead feeder	Number (times)	5	16	7	7
	Average time/AEDI (min.)	0.01	0.01	0.32	0.32
	Total time (min.)	2.067	35.47	9.07	46.61

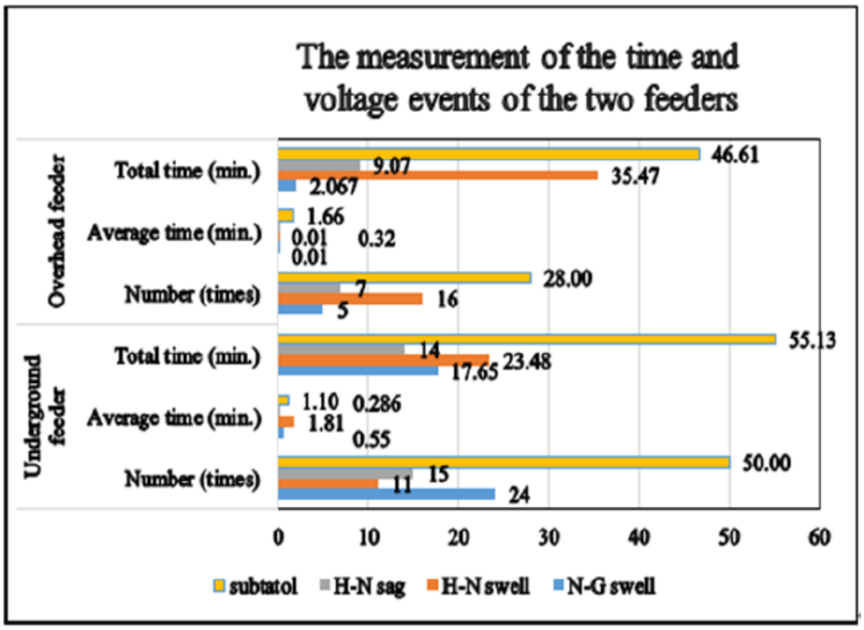


Fig.16.The measurement of the time and voltage events of the two feeders.

VI. CONCLUSION

It is selected two different types of distribution system for underground feeders and overhead feeders in the micro grid and install voltage events recorders to measure and record their voltage events which including voltage swell, voltage sag, power interruption, voltage transient and frequency variation, etc. The period of the dose is 12 weeks about three months. Innovation defines the power performance index which covers the two indexes as the interruption performance index and the events performance index. From the view of reliability infer, one uses the voltage interruption data to derive the average interruption duration index (AIDI) and the other uses the voltage swell and voltage dip data to derive the average event duration index (AEDI).

The measurement results are divided into two phases: (1). The total number of events during the measurement period of underground feeder measurement is 166 times, of which the voltage transient is 80 times as highest, the voltage swell is 36 times as second highest and the voltage swell is 36 and the power interruption is 35 times as the third highest. (2). The total number of events during the measurement period of overhead feeder measurement is 230 times, of which the voltage transient is 168 times as highest, the voltage swell is 54 times as second highest and the voltage swell is 36 and the power interruption is 5 times as the third highest.

The power performance index derivation distinguishes between two sides: (1) The AIDI and AEDI of underground feeders are 75.66 min. and 1.10 min., separately. (2) The AIDI and AEDI of overhead feeders are 10.53 min. and 0.32 min., individually.

The events required by an ideal power supplier and user need to approach zero and the power performance indexes of AIDI and AEDI are close to zero. The development of AIDI and AEDI is to evaluate the power quality of supply-side and demand-side. There are a very long distance between AIDI and AEDI for two different types of underground and overhead feeders to improve the power quality that mean both feeder have bad power quality. Furthermore, based on the proceeding of measurement derive that the overhead feeder has better power quality and better reliability.

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