An enhanced scheme for detecting under-voltage and over-voltage using fuzzy logic based system in a low voltage grid network

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Abstract - *Electricity distribution is the final stage in the delivery of electricity from generating power plants to end users. A distribution system's network carries electricity from the transmission system and delivers to its load centres. It is the most visible part of the power supply chain, and as such the most exposed to the critical observation of its users. Thus, it is very important to have high reliability, high efficiency and high service quality in the low tension distribution grid. In order to have such a system, improvement in power quality is paramount; in this paper a simulation based graphic user interface is proposed to detect under-voltage and over-voltage disturbance events in a three phase secondary distribution grid with a proper data logging capability to effectively record the voltage variation. At present, a system to monitor the low voltage distribution system in Nigeria does not exist. A fuzzy logic based system of real time remote monitoring of the secondary side of 100 KVA 11 KV/.415 KV low voltage distribution network lines via a remote channel is proposed to detect any under-voltage and over-voltage to the end users. The whole system is based on user friendly Proteus simulator interface communicating with measuring devices through a remote terminal unit (RTU). By using this developed scheme, under-voltage and over-voltage can be detected with minimal absolute error value.*

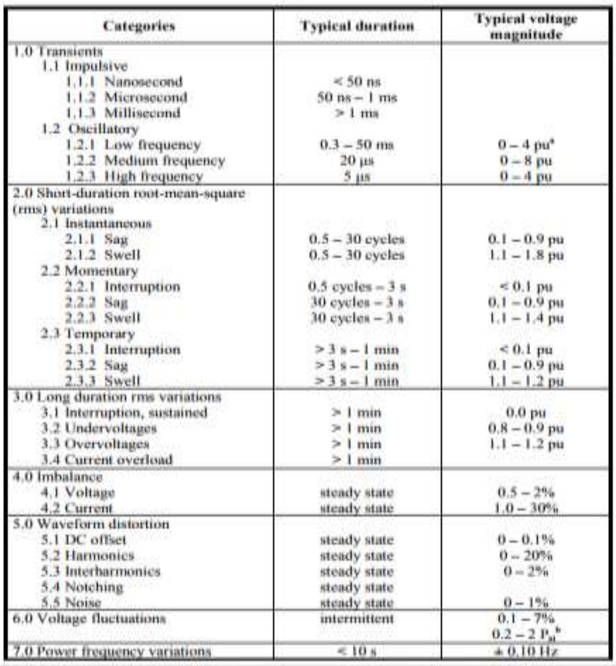
Key Words: **Low voltage distribution system, under-voltage, over-voltage, Proteus simulator, remote terminal unit, graphic user interface, measuring devices, fuzzy logic based system**.

INTRODUCTION

Electricity demand especially in third world countries like Nigeria is at an all-time high due to industrialization and population increase. Major concerns and monitoring are turned to generation and transmission sections of the grid to curb losses with little attention paid to distribution grid especially the low voltage secondary distribution grid where the voltage level is of the main consideration. Surveys have shown that under-voltage and over-voltage are considered as the dominant factor affecting power quality which are disruptive and damaging to equipment and house hold appliances that are sensitive to distortion of voltage as a lot of money could be saved by monitoring each of the three phases of the low distribution system (415V phase to phase) to detect and report these power quality disturbances. To improve power quality, it is required to detect disturbances, identify sources of power system disturbances and find solution to mitigate them. This paper proposes an enhanced scheme of using a fuzzy logic system based Proteus interface to detect under-voltage and over-voltage power quality events in the secondary side of 11 KV (Kilo-Volt)/.415 KV 100 KVA (Kilo-Volt Ampere) low voltage distribution grid network.

TYPES OF POWER QUALITY DISTURBANCES

Table -1: Categories and Typical Characteristics of Power System Electromagnetic Phenomena



Categories	Typical duration	Typical voltage magnitude
1.0 Transients		
1.1 Impulsive		
1.1.1 Nanosecond	< 50 ns	
1.1.2 Microsecond	50 ns – 1 ms	
1.1.3 Millisecond	> 1 ms	
1.2 Oscillatory		
1.2.1 Low frequency	0.3 – 50 ms	0 – 4 pu^a
1.2.2 Medium frequency	20 µs	0 – 8 pu
1.2.3 High frequency	5 µs	0 – 4 pu
2.0 Short-duration root-mean-square (rms) variations		
2.1 Instantaneous		
2.1.1 Sag	0.5 – 30 cycles	0.1 – 0.9 pu
2.1.2 Swell	0.5 – 30 cycles	1.1 – 1.8 pu
2.2 Momentary		
2.2.1 Interruption	0.5 cycles – 3 s	< 0.1 pu
2.2.2 Sag	30 cycles – 3 s	0.1 – 0.9 pu
2.2.3 Swell	30 cycles – 3 s	1.1 – 1.4 pu
2.3 Temporary		
2.3.1 Interruption	> 3 s – 1 min	< 0.1 pu
2.3.2 Sag	> 3 s – 1 min	0.1 – 0.9 pu
2.3.3 Swell	> 3 s – 1 min	1.1 – 1.2 pu
3.0 Long duration rms variations		
3.1 Interruption, sustained	> 1 min	0.0 pu
3.2 Undervoltages	> 1 min	0.8 – 0.9 pu
3.3 Overvoltages	> 1 min	1.1 – 1.2 pu
3.4 Current overload	> 1 min	
4.0 Imbalance		
4.1 Voltage	steady state	0.5 – 2%
4.2 Current	steady state	1.0 – 30%
5.0 Waveform distortion		
5.1 DC offset	steady state	0 – 0.1%
5.2 Harmonics	steady state	0 – 20%
5.3 Interharmonics	steady state	0 – 2%
5.4 Notching	steady state	
5.5 Noise	steady state	0 – 1%
6.0 Voltage fluctuations	intermittent	0.1 – 7% 0.2 – 2 P_{st}^{b}
7.0 Power frequency variations	< 10 s	± 0.10 Hz

Disturbances in low voltage distribution are caused by flickers, harmonics, oscillatory frequencies, transients, noise, interruptions as well as short duration and long duration variations of under-voltage and over-voltage.

The fuzzy logic based system can detect short and long duration variations of under-voltage and over-voltage where one-half cycle under-voltage followed by one cycle of over-voltage will not be reported as one event.

HARDWARE MEASURING DEVICES

In this paper Zelisko 3 x SMVS-UW1001 (voltage sensor) are retrofitted to the switchgear of the secondary side of 100 KVA 11 KV/415V distribution networks of urban or rural areas. The measuring sensors are implemented in order to monitor voltage levels. The compact sensors of Zelisko enable an easy and quick retrofit without major changes in the switch-gear and in the network infrastructure.

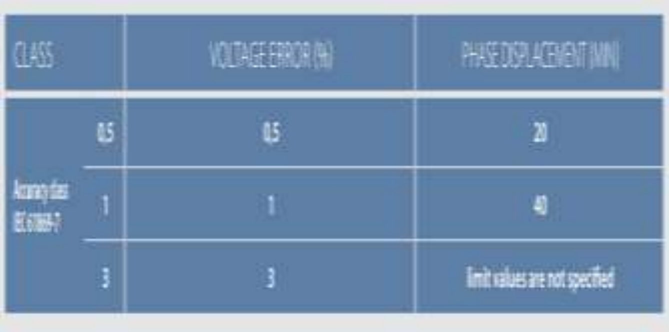
Benefits of implementing Zelisko sensors:

- **High measurement accuracy** without on-site calibration.
- **Simple installation of U-sensors** in original equipment.
- **Simple retrofitting of old facilities** without major modifications of the local network substations
- **High reliability** even for application in harsh environmental conditions.
- **Measuring signal** according to international transformer standards / IEC standards

These enable monitoring and detection of network under-voltage and over-voltage conditions and cost savings due to:

- Low investment costs.
- Cost-effective retrofitting of old facilities.
- No on-site calibration necessary.

Table -2: Accuracy limits of Zelisko voltage sensors for measurement purposes



CLASS		VOLTAGE ERROR (%)	PHASE DISPLACEMENT (MIN)
Accuracy class IEC 61869-7	0.5	0.5	20
	1	1	40
	3	3	limit values are not specified

The accuracy of the sensors, i.e. the absolute value error and phase error, is constant over the lifetime and has not to be recalibrated or readjusted. The calibration to the desired nominal and secondary voltage is performed originally at the manufacturers.

The voltage sensor is suitable for both, original equipment and retrofitting, without any reconstructions of network stations necessary.

DATA COMMUNICATIONS

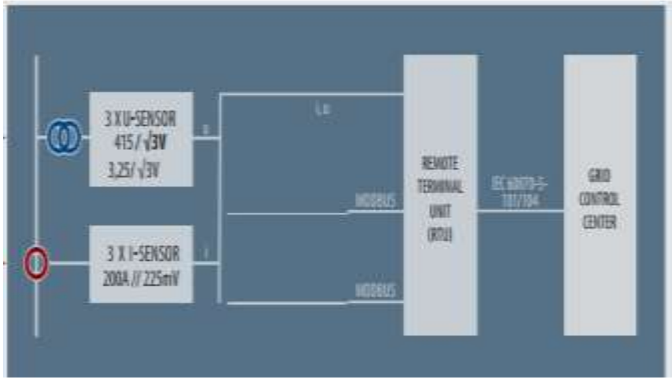


Figure -1: Schematic of The communication system of the proposed system.

Transmission of the instantaneous values of voltage transducers directly to analogue RTU inputs through MODBUS and in turn RTU communicates to grid control center equipped with high speed analogue to digital converter (AD817) and a low pass digital signal processing filter to minimize noise. The instrument transformers (potential transformers) provide protection to the sensors.

MATHEMATICAL CHARACTERIZATION

The 3-phase RMS values are calculated and used in detection of preset values for under-voltage and over-voltage disturbance events. Where;

$V_{PU}= V/V_{BASE}$

V_{RMS}= 230VAC=1 p.u (phase voltage)

- Secondary distribution of 100 KVA 11KV/415V rating is assumed as the network for this paper.
- S_{BASE} = Power rating of the distribution transformer of 100KVA
- $I_{BASE} = S_{BASE}/V_{BASE}$ = 1 p.u
- KVA per phase= 100KVA/3 = 3.3333 KVA 3.33333KVA/230V =145 A
- I_{RMS} per phase=145 A approximately 200 A
- Per-unit volt = volts/ base volt
- Per-unit ampere = ampere/base ampere

In the three phase distribution network:

- Base ampere = Base KVA x 1000/square root of 3 x base volts

The RMS value for each phase (V_{RMS}) is calculated by the program for the jth Cycle.

$$V_{RMS}(j) = \sqrt{\frac{1}{N}\sum_{k=jN}^{(j+1)N-1} v^2(k)} \quad \{2\}$$

j = period number (integer)

N = number of samples per cycle (integer)

v = value of voltage at sample k

The window of N samples is then shifted forward in time by one-half cycle and the RMS value is again calculated for one cycle. Shifting the window one-half cycle at a time provides "a convenient measure of the magnitude evolution". An acceptable voltage range is calculated based on the nominal voltage and specified tolerances. If a single-cycle RMS voltage value does not fall within the acceptable range, it is categorized as part of a disturbance. The next RMS value, the samples for which were taken after a one-half cycle time shift, is then compared to the acceptable voltage range. Once an RMS value within tolerances is found, the event is deemed to be over.

- Voltage sag = has a RMS value equal or less than 0.9 p.u of 230 V (nominal voltage) =>207 V.
- Voltage swell = has a RMS value equal or greater than 1.1 p.u of the nominal voltage value =<253 V.
- Under-Voltage = voltage sag that lasts for more than 1 minute.
- Over-Voltage = Voltage Swell that last more than 1 minutes.

The duration of both is at least 0.5 cycles. Single-cycle RMS values are calculated using equation [1] and are stored. Each single-cycle voltage value is compared to that phase's nominal RMS value. If the single-cycle value is within tolerances, the program moves to the next RMS half-cycle value if the value is outside of the specified tolerances, the program recognizes a disturbance and displays the RMS voltage through a virtual terminal and a LED (light emitting diode) indicator for the particular phase. The program considers a disturbance to have ended when the subsequent RMS voltage value in that phase is within acceptable limits. It then continues to examine the generated files for more disturbances until all cycles have been checked.

FUZZY LOGIC BASED PROTEUS SIMULATION INTERFACE

The Rms calculations determine the membership function of under-voltage, over-voltage and normal voltage where:

R_1 = Normal voltage is greater than 0.9 p.u and lesser than 1.1 p.u of the nominal voltage (230V).

R_2 = Voltage sag is lesser than or equal to 0.9 p.u of the nominal voltage (230V).

R_3 = Voltage swell is greater than or equal to 1.1 p.u of the nominal voltage (230V).

The fuzzy rule is based on the "IF-Then" constructions, which can be described as:

If x_1 is A_1 and x_2 is A_2 … x_n is A_n then y is B

Where A_i (I = 1, 2,…, n) and B are linguistic values.

A Fuzzy Expert System contains two major parts: fuzzy sets and a fuzzy rule base, the concept of fuzzy sets was proposed by L.A. Zadeh in 1965. Given a fuzzy set A, let x ∈ U be the elements, a membership function (MF) μ_a (x) presents if x belongs to A, expressed as:

$$A = \{(x, \mu_A(x)), x \in U\} \qquad \{2\}$$

The three phases' voltages are classified using these rules from normal, under-voltage and over-voltage set voltage values.

The voltage elements are:

R_P = red phase

Y_P = yellow phase

$B_{P\,=}$ blue phase

And

$R_{1=}$ Normal Voltage Range i.e 207V < x < 253V

R_2= Under-Voltage Range i.e x<= 207V

R_3= Over-Voltage Range i.e x>= 253V

The logic for disturbance detection accounts for the three phases simultaneously as follows:

[1] If R_P is R_2, Y_P is R_2 and B_P is R_2 then $T = T_1$

[2] If R_P is R_3, Y_P is R_3 and B_P is R_3 then $T = T_2$

[3] If R_P is R_2, Y_P is R_2 and B_P is R_1 then $T = T_3$

[4] If R_P is R_3, Y_P is R_3 and B_P is R_1 then $T = T_4$

[5] If R_P is R_2, Y_P is R_1 and B_P is R_2 then $T = T_5$

[6] If R_P is R_3, Y_P is R_1 and B_P is R_3 then $T = T_6$

[7] If R_P is R_2, Y_P is R_1 and B_P is R_1 then $T = T_7$

[8] If R_P is R_3, Y_P is R_1 and B_P is R_1 then $T = T_8$

[9] If R_P is R_1, Y_P is R_2 and B_P is R_2 then $T = T_9$

[10] If R_P is R_1, Y_P is R_3 and B_P is R_3 then $T = T_{10}$

[11] If R_P is R_1, Y_P is R_2 and B_P is R_1 then $T = T_{11}$

[12] If R_P is R_1, Y_P is R_3 and B_P is R_1 then $T = T_{12}$

[13] If R_P is R_1, Y_P is R_1 and B_P is R_2 then $T = T_{13}$

[14] If R_P is R_1, Y_P is R_1 and B_P is R_3 then $T = T_{14}$

[15] If R_P is R_1, Y_P is R_1 and B_P is R_1 then T = T_{15}

The voltage disturbance detection system produces an output "T" from each sampling oscillation at the rate of 1-2 seconds interval from the three phases which could give a result range of T_1 to T_{15}, where:

[a] T_1= All the three phases are below the normal voltage range.
[b] T_2=All the three phases are above the normal voltage range.
[c] T_3=The red and yellow phases are both below the normal voltage range while only the blue phase is within the normal voltage range.
[d] T_4=The red and yellow phases are both above the normal voltage range while only the blue phase is within the normal voltage range.
[e] T_5=The red and blue phases are both below the normal voltage range while only the yellow phase is within the normal voltage range.
[f] T_6=The red and blue phases are both above the normal voltage range while only the yellow phase is within the normal voltage range.
[g] T_7=Only the red phase is below the normal voltage range while the yellow and the blue phases are both within the normal voltage range.
[h] T_8=Only the red phase is above the normal voltage range while the yellow and the blue phases are both within the normal voltage range.
[i] T_9=Only the red phase is within the normal voltage range while the yellow and the blue phases are both below the normal voltage range.
[j] T_{10}=Only the red phase is within the normal voltage range while the yellow and the blue phases are both above the normal voltage range.
[k] T_{11}=The red and blue phases are both within the normal voltage range while only the yellow phase is below normal voltage range.
[l] T_{12}=The red and blue phases are both within the normal voltage range while only the yellow phase is above normal voltage range.
[m] T_{13}=The red and yellow phases are both within the normal voltage range while only the blue phase is below the normal voltage range.
[n] T_{14}=The red and yellow phases are both within the normal voltage range while only the blue phase is above the normal voltage range.
[o] T_{15}=All the three phases are within the normal voltage range.

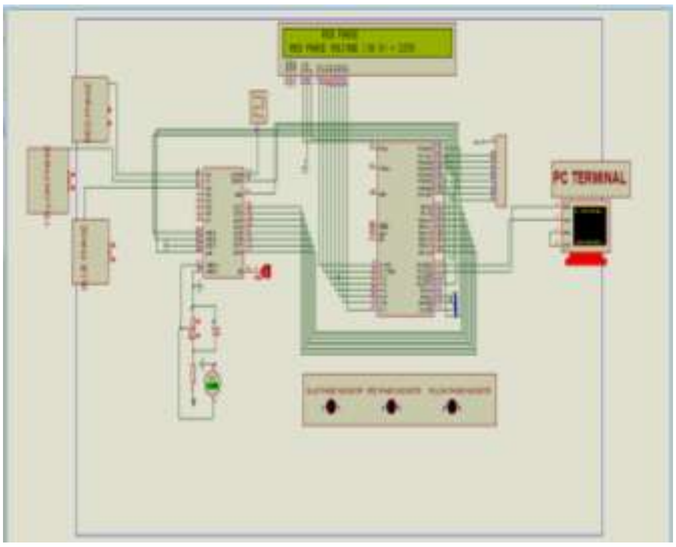
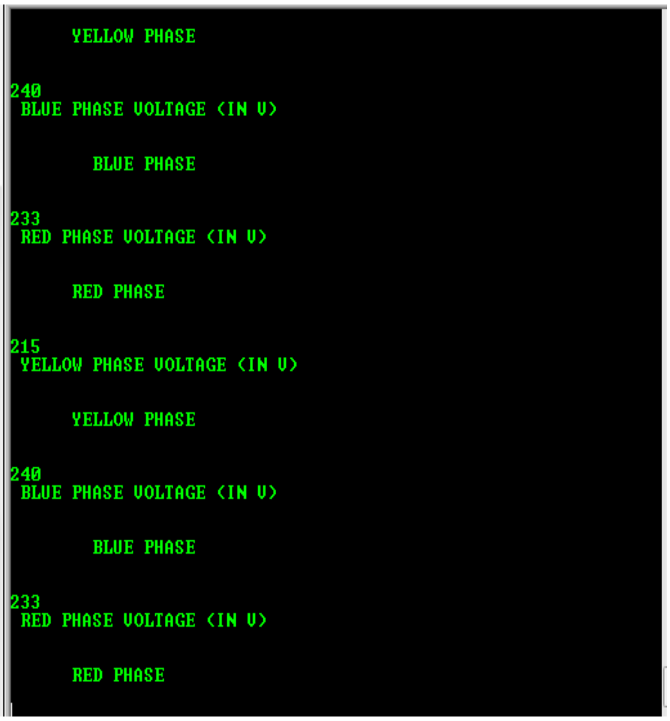


Figure -2: Schematics build up of Proteus Simulator



```
     YELLOW PHASE

240
 BLUE PHASE VOLTAGE (IN V)

       BLUE PHASE

233
 RED PHASE VOLTAGE (IN V)

     RED PHASE

215
 YELLOW PHASE VOLTAGE (IN V)

     YELLOW PHASE

240
 BLUE PHASE VOLTAGE (IN V)

       BLUE PHASE

233
 RED PHASE VOLTAGE (IN V)

     RED PHASE
```

Figure -3: Proteus Simulator User Interface.

SIMULATION TEST AND RESULT

MATLAB/Simulink sim power system tool boxes was used to generate disturbance events at 50 Hz frequency at different instances among the three (3) distribution phases programmed with fuzzy logic giving a total of 15 logical outputs. Generated Test disturbance is simulated to check for the accuracy of each given output for detection. Voltages were also tested at border line limits for under-voltage and over-voltage to check for sensitivity and accuracy.

For Interfacing Proteus with Matlab we need additional software (Virtual serial Ports Emulator) for making virtual com port and making pairing between the two ports possible.

Table -3: Non-Proximity range disturbance detection.

Power Quality Event	Voltage Range	File Detection
Normal Voltage	220-240	50/50
Under-voltage/Sag	0-190	50/50
Over-Voltage/Swell	270-460	50/50
Total		150/150

Random selection of voltage values where generated across the range to check for sensitivity.

Table -4: Border-line Proximity range disturbance detection

Power Quality Event	Voltage Range	Detection
Normal Voltage	208	9/10
	209	10/10
	210	10/10
	211	10/10
	212	10/10
Under-Voltage/Sag	207	8/10
	206	10/10
	205	10/10
	204	10/10
	203	10/10
Over-voltage/swell	253	9/10
	254	10/10
	255	10/10
	256	10/10
	257	10/10
Total		146/150

CONCLUSION

The Proteus Simulation program detected all generated voltage disturbances across values not close to borderline and Electrical noises were also excluded from simulation tests. The possibility exists that a false disturbance will be detected if the voltage rises slowly, perhaps due to load shedding, during the timeframe in which data was recorded. Secondly, spikes in voltage may not be detected in files with high sampling frequencies. In such files, one data point does not carry as much weight in RMS calculations as it does in files with lower sampling frequencies. Thus, the higher the sampling frequency, the higher a spike must be to cause one cycle's RMS value to exceed the threshold which constitutes a disturbance. A user with understanding of power quality would be able to comprehend and rectify these problems by plotting the voltage files graph.

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