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Design and Behavioral Analysis of an Automatic Phase Selector in a Low-Voltage Distribution Grid for the Elimination of Service Faults: A Case of the Catholic Grid Hewa-Bora Lubumbashi, DRC

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Abstract: **Manual phase change in a low voltage distribution grid is becoming a major problem. It is the cause of most domestic incidents such as the deterioration of appliances, fires, etc. An effective way to avoid these incidents is to be able to make phase changes without human intervention in the event of an anomaly or fault on the grid. This work therefore addresses the problem of manual phase change in a domestic installation using an automatic phase selector. The proposed solution uses voltage sensors, a programmable electronic card, a display as well as electromagnetic relays. After analyzing the solution with data science using python, the result shows that the designed system can positively help the distribution grid by autonomously managing certain parameters.**

Keywords: **Phase selector, phase change, anomaly, data science, fault, low voltage grid, installation.**

I. INTRODUCTION

Faults such as untimely cuts (of the 3 phases) are most of the time without danger for the installation (the electrical grid) and the subscribers because they do not push the latter to manipulate the installations unlike other faults (cuts of a phase, voltage drop, etc.) which push them to have hand in the connections on the divisional panel in order to connect the installation to the phase offering better quality energy compared to the others. These interventions in installations are in some cases carried out by amateurs or people who have practically no qualifications in electricity. These actors are potential authors of damage (deterioration of equipment, fire, etc.) in installations because they are unaware of the importance of a tight contact point, the position of the neutral wire in an installation etc. Thus, given the undeniable existence of faults such as untimely power cut, severe voltage drops, voltage variations, voltage unbalance in the low voltage distribution grid of the SNEL Hewa Bora Lubumbashi Catholic Line; our article is part of the elimination of faults in this grid thanks to the design and behavioral analysis of an automatic phase selector.

Thanks to the evolution of automation technologies, many researchers have thought of implementing phase selectors which are devices capable of automatically selecting the phase (or phases) to which to connect the load without any human intervention. These researchers focused their research on the design and construction of this device based on the presence or absence of voltage in the phases without taking into account their amplitude. In addition, their studies do not address the

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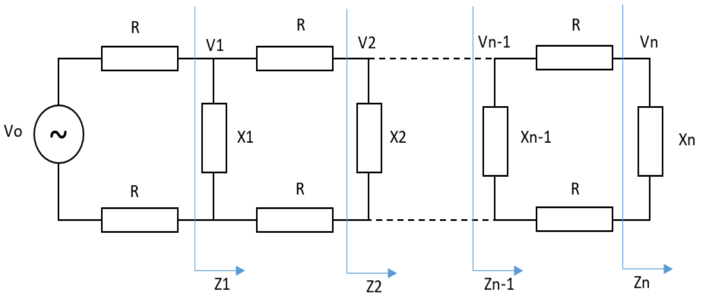
behavioral aspect and the impact of such devices in the grid, they were limited to analyzing the operation of the phase selector as an isolated device not part of a larger system (electrical grid) [1], [2], [3], [4], [5]. Although their results are conclusive, we believe that a grid comprising more than one phase selector must be the subject of a particular look at these aspects because the connection of single-phase loads on a 3~ line could potentially be the cause of the unbalances due to unequal system impedances, unequal distribution of single-phase loads, etc. [6], [7], [8], [9]. Our study therefore addresses the behavioral aspect of the grid (voltage drop, voltage unbalance) and phase selectors (selection stability) in order to determine the impact of the latter on the quality of energy in distribution (fault elimination).

The objectives of this study are therefore: (1) model a 3~ distribution grid and produce a model for calculating voltage drops using the analytical method and simulation; (2) design and produce an automatic phase selector taking into account the quality of energy (mainly the voltage amplitude) on the 3 phases in subscriber installations; (3) analyze the stability of the phase selectors and the voltage drops (unbalance) in the grid thanks to data analysis using python.

II. METHODOLOGY

We began this study with a modeling of a low voltage distribution grid in order to generalize the evolution of line voltage drops as a function of line resistance and impedances (loads) of subscribers as illustrated in Figure 1. We arrived at a mathematical model for calculating voltage drops in a grid given by equations 1 below:



$$V[n] = V[n-1]\frac{Zeq[n]}{2R + Zeq[n]} \quad (1)$$

$$Zeq[n] = \frac{X[n](2R + Zeq[n+1])}{X[n] + (2R + Zeq[n+1])} \quad (2)$$

Fig. 1. Single-phase model of a 3~ distribution line (Phase-Neutral)

We then produced an algorithm for calculating voltage drops which we converted into a python program then tested (verified) and validated using the analytical method and simulation in the Multisim software.

After modeling, we designed the phase selector based on the voltage amplitude of different phases whose circuit diagram given in Figure 2 and the selection algorithm in Figure 3.

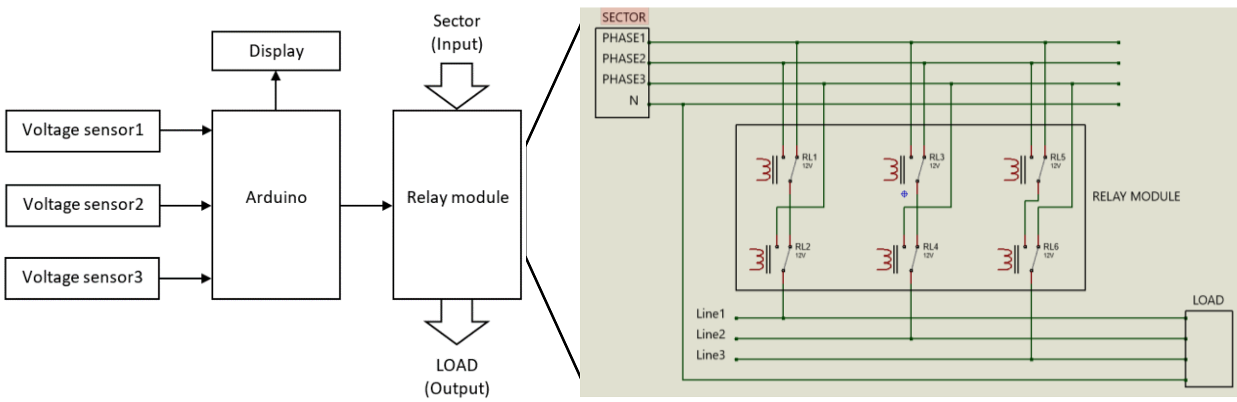


Fig. 2. Automatic phase selector circuit diagram

For the behavioral analysis of the selector, we used the longest line of the low voltage distribution grid of the Catholic cabin of the HEWA BORA Lubumbashi district for which we brought out an approximate diagram given in Figure 4 by the observation method. For our study, the chosen departure goes from the cabin then divides into two at the level of an apparent

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disconnection box. We considered one of the two lines starting from the disconnection box given that the distance between the cabin and said box is not too great. Through this same field trip, we collected information by interviewing 20 subscribers of this grid which served as input data for our analysis. The summary of this information is given in tables 1 and 2. We finally used a data analysis structure based on data science in order to analyze the behavior and impact of our selector phase on a distribution grid.

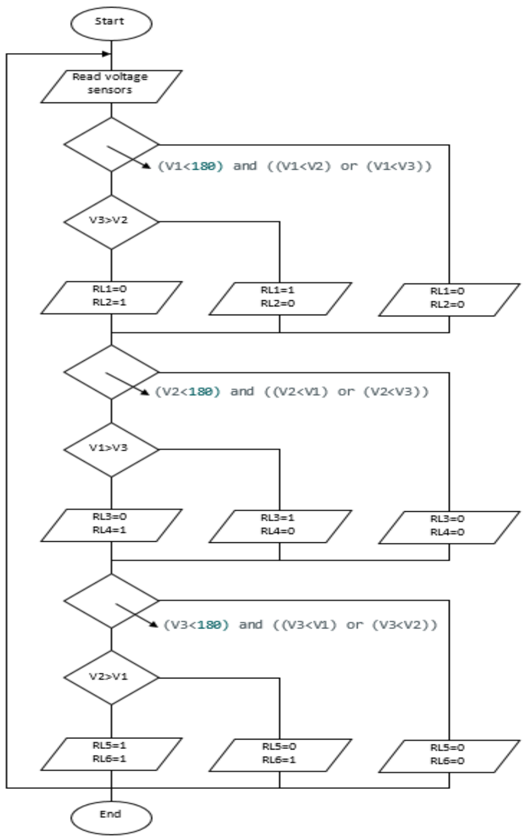

Fig. 2. Selection algorithm of the automatic phase selector

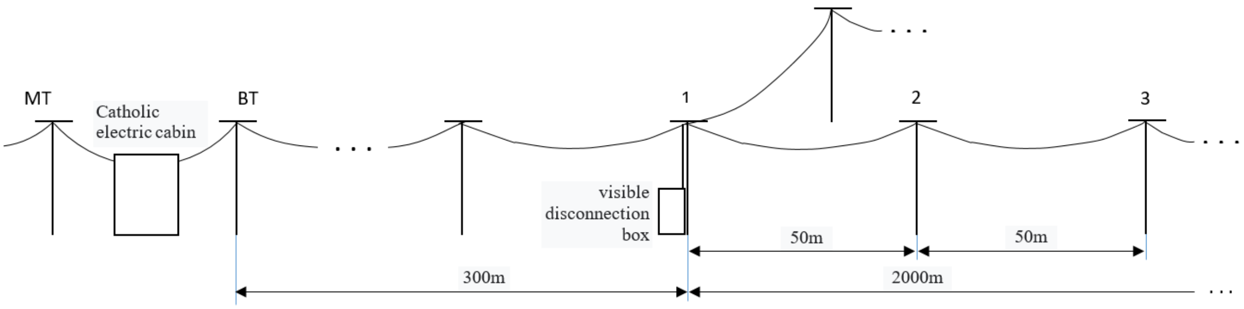

Fig. 3. Approximate diagram of the longest departure of the Catholic Hewa Bora network

Table 1: Summary of the characteristic parameters of the line and subscribers

N°	PARAMETER	VALUE
1	Line length	~ 2000 m
2	Line section	95 mm^2
3	Distance between electric pole / Total number of poles	50 m / 41
5	Average number of subscribers connected to a pole	2
6	Total number of subscribers on the line	~ 82

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Table 2: Summary of subscriber categories and possible power distribution scenario between phases

N°	DEVICE	POWER [W]	1ST CATEGORY			2ND CATEGORY		
			Ph1	Ph2	Ph3	Ph1	Ph2	Ph3
1	TV	~ 100	✓				✓	
2	Lighting	~ 100	✓				✓	
3	Refrigerator	~ 600	✓					✓
4	Iron	1500		✓			✓	
5	Kettle	1500						✓
6	Stove (two plates)	3000				✓		
7	Water Fountain	~ 600					✓	
8	Immersion heater	1500			✓			
TOTAL [W] /PHASE			800	1500	1500	3000	2300	2100
TOTAL INSTALLED POWER			**3800W**			**7400W**		

- Subscribers category 1: ~68 %
- Subscribers category 2: ~25 %
- Other categories: ~7 %

III. RESULTS

3.1 Realization

The result of producing the phase selector is given in Figure 5 below:

Fig. 4. Front view of the phase selector

3.2 Imbalance rate

The diagram in Figure 6 shows the result of the analysis of the evolution of voltage drops on the line for 76 subscribers (connected two by two on each line support) according to 5 different scenarios given in Table 3.

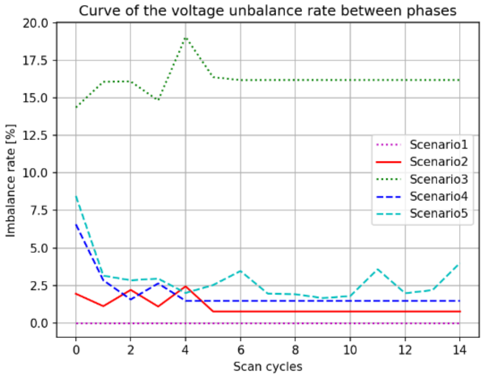

Fig. 5. Curve of the voltage unbalance rate between phases

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3.3 Stability of selectors

The diagram in Figure 7 illustrates the result of the behavior analysis of 76 selectors connected in parallel two by two on line following the same previous scenarios.

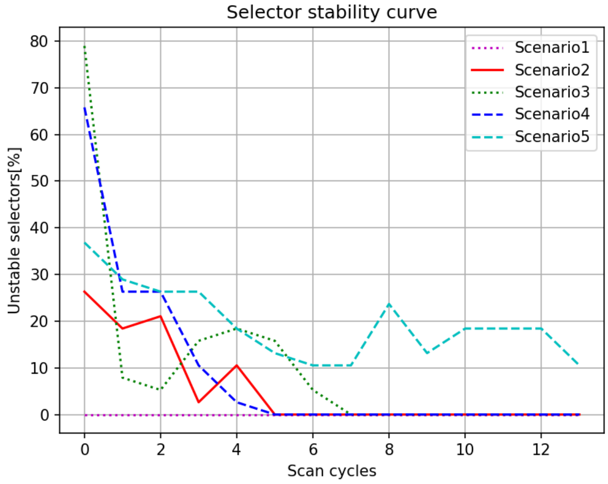

Fig. 6. Curve of phase selector stability

3.4 Power distribution

Below, Figure 8 presents 5 power repair scenarios between phases for a total power of 375.2kW when the selectors are all stable.

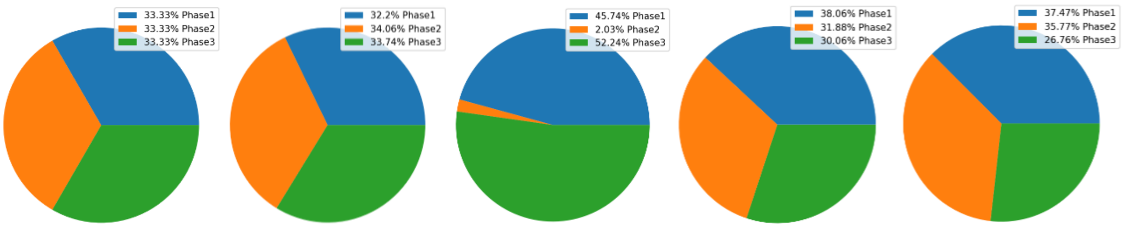

Fig. 8. Diagram of power distribution between phases

IV. DISCUSSION

4.1 Phase selector

The main parameter on which the phase selection of our system is based is the voltage amplitude. Under normal 3~ voltage (220V to 240V), the phase selector connects the load to the 3 phases according to the power distribution in the installation. At this stage, the installation behaves as if the phase selector does not exist. When the grid presents an anomaly in terms of voltage drop or total absence of voltage in one or two phases, the selector comes into play by connecting the faulty line to the phase with the highest voltage level based on the algorithm presented in Figure 3.

This way of proceeding presents a considerable advantage on voltage balancing compared to the selectors which only focuses on the presence of the voltage in one phase or another without taking into account their amplitude, and which in addition always connects the load in 1~ even when the network does not present any anomaly.

4.2 Phase selector and electrical grid analysis

The behavioral analysis of the stability of the selectors, the rate of unbalance between phases of the grid as well as the distribution of power on the grid was carried out on 5 different scenarios representing cases of anomaly and relevant situations that can be meet on a distribution grid. Table 3 below gives an overview of the analysis scenarios used.

Table 3: list of scenarios used for the analysis

N°	Scenario	Description
1	Scenario1	Grid with perfectly balanced loads
2	Scenario2	Grid with load following the distribution in table 2
3	Scenario3	Grid with load following the distribution in table 2 and one of the 3 phases at 140V
4	Scenario4	Grid with all loads in the subscriber installation connected to a single line
5	Scenario5	Grid with all loads in the subscriber installation connected on 2 lines

4.2.1 Stability of selectors

Stability here refers to a state where all selectors manage to keep a fixed selection position (relay combination). This stability on the grid is linked to the voltage level of each phase as well as the voltage difference between phases. As long as the voltage measured by the selector is greater than 180V, the selector considers that the grid is in normal situation (no anomaly) and remains in a stable state by letting each phase normally supply the load connected on it.

On the line, we found that the selectors closest to the cabin (departure) are the most stable and those furthest away are less stable. The closer the load is to the cabin, the lower the line voltage drop. We therefore find voltages greater than 180V near the start and the further away we go, the voltages in the 3 phases drop disproportionately (depending on the power distribution) thus causing phase changes in the selectors.

With a tolerance of +/- 5V of voltage difference between phases, the results show that as long as the sector voltages are lower than 180V and the voltage difference between phases greater than 5V, the selectors are unstable; and when all the selectors reach a stable state, that means at 0% of the unstable selectors, we observe a voltage difference between phases less than 5V, that represent an imbalance rate less than 2% of the supply voltage for a 220V-3~ grid.

4.2.2 Voltage unbalance rate between phases

The unbalance rate allows to determine the largest voltage gap that exists between phases in a 3~ grid. The smaller this rate, the more the gap tends towards zero. For the selectors, although they are independent of each other (do not communicate), diagram 6 shows that the latter tend to stabilize when the voltages between phases are more or less balanced. Besides, in the stable state of the selectors the rate of voltage imbalance between phases is less than 2% when the 3 phases are present regardless of the power distribution in the installation. In the event of an absence of voltage in one or two of the 3 phases, an imbalance rate ranging from ~150% to 300% of the mains voltage is observed.

The margin of the imbalance rate of our system is better compared to the observation made on the grid of the Catholic cabin without phase selector which goes at times beyond 20% of the mains voltage with the 3 phases present. Compare to the automatic phase selectors proposed by other researcher [1], the rate of our selector is better controlled; which is a very significant improvement.

4.2.3 Power distribution between phases

Indirectly, the power is linked to the stability of the selectors because it has a direct influence on the line voltage drops. As a result, the more the powers between phases are disproportionate, the more the voltage levels in the 3 phases are also disproportionate, which has the consequence of causing phase changes at the level of the selectors (instability). Thus, with the 3 phases present, when the selectors stabilize after 5 to 50 scanning cycles (~5 to 50 sec) depending on the complexity of the load, we observe a power distribution between phases with the gap varying between 0 and 10% of the total power present on the grid; and in the event of the absence of one or two phases this gap can go beyond 50% of the total power between the active phases and the absent phase.

V. CONCLUSION

This project of design and behavioral analysis of phase selector in distribution grid allowed us to understand that without any human intervention, automatic phase selectors can have a positive contribution in a low voltage distribution grid by reducing the imbalance rate, by distributing the total power on the grid in a +/- balanced manner while remaining stable in their operation.

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However, there are deadlock situations for which the selectors cannot find a good solution. This is the case when we have to deal with loads having too large power gap. Also, since the selectors do not communicate with each other, an additional load in the network (iron, freezer, etc.) can cause shifts (changes) of phases on several selectors (instability) on the same grid. Thus, a solution to this can be the design of connected phase selector capable of interchanging information on the same grid which can guarantee a selection of phases based on power (power distribution) and a change of phases coordinated in the selectors.

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