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Performance Operation of Circuit Breakers and Feeders

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Abstract: *Circuit breakers (CBs) are very important elements in the power system. They are used to switch other equipment in and out of service. Circuit breakers need to be reliable since their incorrect operation can cause major issues with power system protection and control such as the advancement of power system; the lines and other equipment operate at very high voltages and carry large currents. This paper deals with the operation of circuit breakers and how they protect the Nigerian power system. Data collected from different feeders at national level were analyzed and results with graphical illustrations showed the normal and abnormal working conditions of circuit breakers in the system.*

Keywords: *circuit breakers, power system, feeders*

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I. Introduction

In an electric power system, switchgear is the combination of electrical disconnects switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply. The very earliest central power stations used simple open knife switches, mounted on insulating panels of marble or asbestos. Power levels and voltages rapidly escalated, making open manually operated switches too dangerous to use for anything other than isolation of a de-energized circuit.

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Circuit breaker was first inspired by the works of American scientist Joseph Henry and English scientist Michael Faraday, the circuit breaker was invented in 1836 by an American, Charles Grafton. An early form of circuit breaker was described by Thomas Alva Edison in an 1879 patent application, although his commercial power distribution system used fuses. Its purpose was to protect lighting circuit wiring from accidental short-circuits and overloads. A modern miniature circuit breaker similar to the ones now in use was patented by Brown, Boveri & Cie in 1924. Hugo Stotz, an engineer who had sold his company, Stotz-Kontakt, to BBC, was credited as the inventor on DRP (Deutsches Reichspatent) 458329. Stotz's invention was the forerunner of the modern thermal-magnetic breaker commonly used in household load centers to this day [1-6].

II. Methodology

The data used in this paper are real data of circuit breakers operated in terms of fault readings at a particular time when the breaker breaks and the time at which it was restored back to the system to assume its normal operation in the Nigeria power systems. Data collected was from the Apo Substation of the Federal Capital Territory Abuja.

In this paper, the graphs to be plotted are;

- ✓ Overcurrent graph
- ✓ Load consumption graph
- ✓ Outage time of feeders.

These graphs are simple illustrations of the operation of circuit breakers in Nigeria power system.

But before the illustrations with graphs are made, let us know the class of outages we have running in the power system as a whole.

III. Principles Of Operation

All circuit breakers have common features in their operation, although details vary substantially depending on the voltage class, current rating and type of the circuit breaker. The circuit breaker must detect a fault condition; in low-voltage circuit breakers this is usually done within the breaker enclosure. Circuit breakers for large currents or high voltages are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism. The trip solenoid that releases the latch is usually energized by a separate battery, although some high-voltage circuit breakers are self-contained with current transformers, protection relays, and an internal control power source.

Once a fault is detected, contacts within the circuit breaker must open to interrupt the circuit; some mechanically-stored energy (using something such as springs or compressed air) contained within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. Small circuit breakers may be manually operated; larger units have solenoids to trip the mechanism, and electric motors to restore energy to the springs.

The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when interrupting (opening) the circuit. Contacts are made of copper or copper alloys, silver alloys, and other highly conductive materials. Service life of the contacts is limited by the erosion of contact material due to arcing while interrupting the current. Miniature and molded case circuit breakers are usually discarded when the contacts have worn, but power circuit breakers and high-voltage circuit breakers have replaceable contacts. When a current is interrupted, an arc is generated. This arc must be contained, cooled, and extinguished in a controlled way, so that the gap between the contacts can again withstand the voltage in the circuit. Different circuit breakers use vacuum, air, insulating gas, or oil as the medium in which the arc forms.

Different techniques are used to extinguish the arc including:

- Lengthening / deflection of the arc
- Intensive cooling (in jet chambers)
- Division into partial arcs
- Zero point quenching (Contacts open at the zero current time crossing of the AC waveform, effectively breaking no load current at the time of opening. The zero crossing occurs at twice the line frequency i.e. 100 times per second for 50 Hz and 120 times per second for 60 Hz AC)
- Connecting capacitors in parallel with contacts in DC circuits.

Finally, once the fault condition has been cleared, the contacts must again be closed to restore power to the interrupted circuit [3].

IV. Arc Phenomenon

When short-circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts usually the medium is oil or air is sufficient to ionize the air or vapourize and ionize the oil. The ionized air or vapour acts as conductor and an arc is struck between the contacts. The potential drop between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path and consequently the current in the circuit remains uninterrupted so long as the arc persists. During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts. The arc resistance depends upon the following factors [7-8]:

- ✓ Degree of ionization-the arc resistance increases with the decrease in the number of ionized particles between the contacts.
- ✓ Length of the arc-the arc resistance increases with the length of the arc i.e, separation of contacts.
- ✓ Cross-section of arc- the arc resistance increases with the decrease in area of X-section of the arc.

V. Circuit Breaker Model

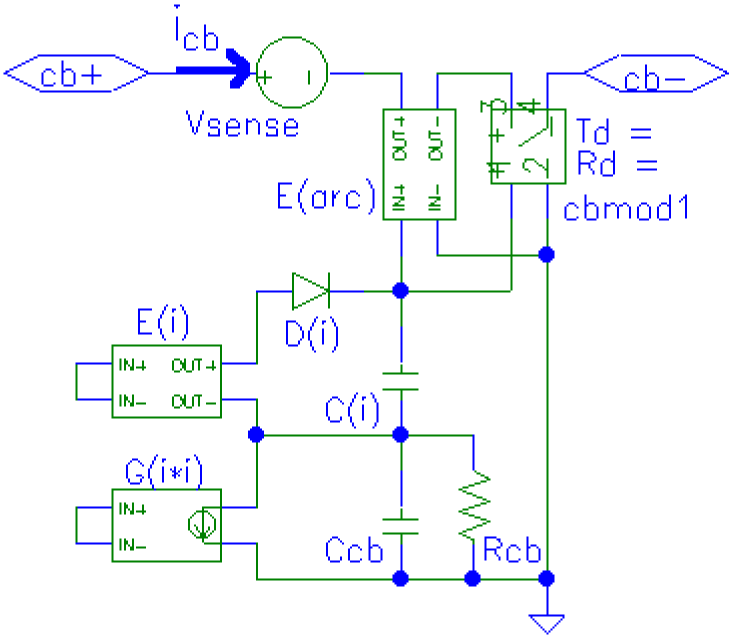

Fig 1: model of a typical circuit breaker.

The circuit-breaker model is shown in Figure 3.1. Current **icb** through the circuit-breaker flows between I/O pins **cb+** and **cb-**, passing through the voltage source **Vsense**, voltage-controlled voltage source **E(arc)** and voltage-controlled switch **cbmod1**. **Vsense** acts as an ideal current meter. To model the thermal characteristic of the circuit breaker, the current **icb** measured by **Vsense** is passed to the current-controlled current source **G(i*i)**, which outputs a current equal to **icb** raised to the power **n**, whenever **icb** exceeds the rated current **ir** of the circuit breaker. The change in voltage developed across **Ccb** is then,

$\Delta V_{Ccb} = \int_{t1}^{t2} G(i * i)dt$ . . . . (5.1)

Where, $G(i * i) = (i_{cb}^{n})$, when $i_{cb} \geq i_r$

$= 0$, when $i_{cb} \leq i_r$

By making the capacitor **Ccb** value equal to the pre-arcing time of the circuit-breaker, the voltage developed across **Ccb** at the end of the pre-arcing time is normalized to 1V. The thermal loss of the circuit breaker is modeled by the resistor **Rcb**, which discharges the voltage across **Ccb**.

To model the magnetic characteristic of the circuit breaker, a voltage source **E (i)**, which is controlled by the current **icb**, outputs a voltage that linearly increases from 0 when the current level exceeds $\mathbf{i_{m1}}$, rising to a maximum of 1V when the current level reaches $\mathbf{i_{m2}}$. The diode **D (i)** and capacitor **C(i)** provide a peak hold function to allow the simulation to proceed in a latching action.

The arc voltage initially generated as the contacts break, **Va**, is modeled by a voltage sourced from **E(arc)**. The voltage-controlled switch **cbmod1** models the DC resistance of the circuit-breaker with closed contacts **Rd**, the resistance increase as the arc extinguishes, and the one-way action of the opening contacts. The input to **E(arc)** and **cbmod1** is the voltage developed across both **Ccb** and **C(i)**. The switch **cbmod1** is a digital sub-circuit which switches off when its controlling input voltage exceeds 1V.

The change in switch resistance during the off transition is controlled by a time delay factor **Td** and a resistance factor **Rd**. Three series connected resistances in **cbmod1** model the circuit-breaker arc resistance increase [9-11].

VI. Grouping Of Outages Into Classes

Power outage is a term used to describe the abrupt power failures that occurs due to abnormal conditions in the system, and these abnormal conditions could be transient faults, overcurrent, load shedding, weather conditions etc.

These outages are

1. Forced outage
2. Pre-arranged outage

3. Emergency outage
4. Customer request outage

FORCED OUTAGES: these are outages caused by uncontrollable conditions in the system such as overcurrent faults, earth faults, drizzling weather conditions etc. when such faults occur in the system it causes the sensing relay to give signal to the appropriate circuit breaker to isolate the faulted area to allow the rest of the system to continue in service.

PRE-ARRANGED OUTAGE: these are outages carried out in the system when there is scheduled plan for maintenance of some vital equipment in the system. And it is done by the operating engineer as at that time to isolate the appropriate area for proper maintenance work to be done.

EMERGENCY OUTAGE: It is done when there is an emergency of fire breakout in a transformer or any part of the system, it is required for the relay to send signal for appropriate breaking of that feeder connected to that transformer so as to save the whole system from damage.

CUSTOMER'S REQUEST: this is done when vital equipment, transmission and distribution lines are been covered up by bushes and need be for clearance, the information could be passed onto the appropriate operator for effective isolation for such maintenance to be carried out.

VII. Results And Discussions

Over current tripping of feeders

Analyzing from figures 1, 2, 3, 4, 5 and 6 which are the over current graphs, we found out that they almost look similar in terms of the time of circuit breakers tripping and when they were brought back online to work as designed. The red bars stands for time out of feeders while the blue bars stands for time in of feeders respectively.

An over current could be caused by earth fault, line to ground or line to line fault as the case may be. When there is an over current in the line, the relays senses it as a fault and signals the appropriate circuit breaker to isolate that faulted area from the remaining part of the system so as to avoid entire system damage. The peak loads on the figures shows more congested areas where those feeders are supplying power to. If there be any break down of circuit breakers it could have adverse effect on those customers in such areas.

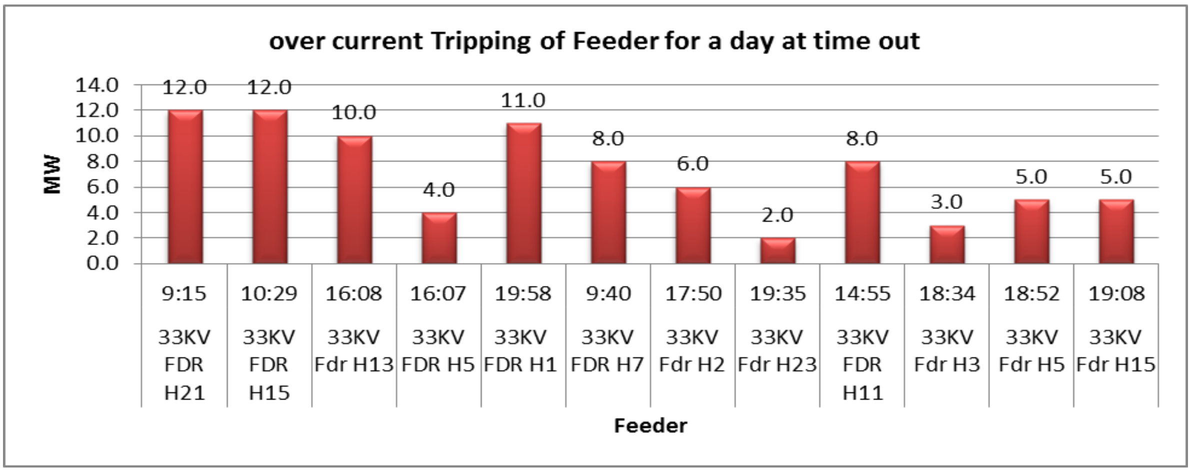

Fig 1: over current tripping of feeder for a day at time out.

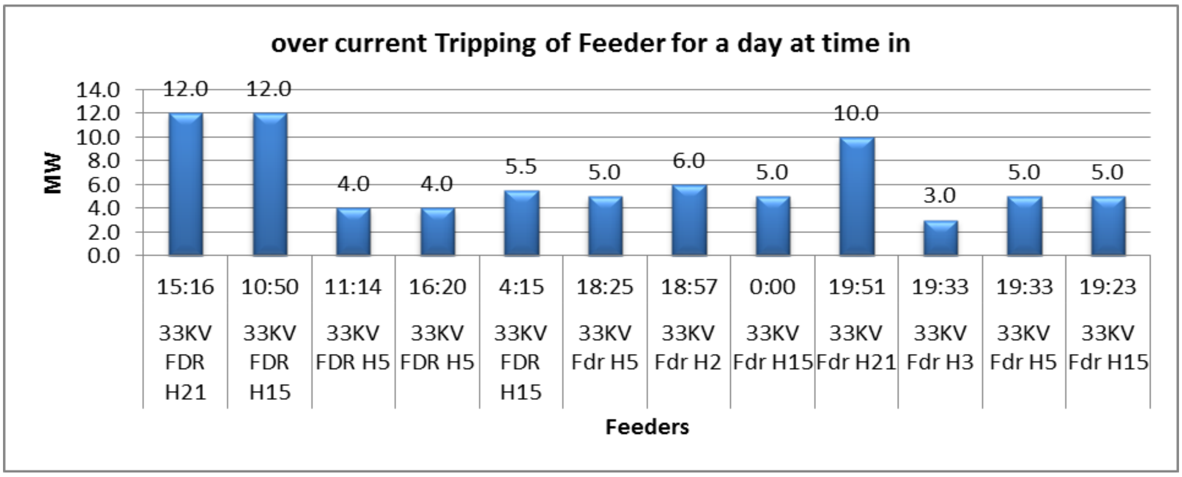

Fig 2: over current tripping of feeder for a day at time in.

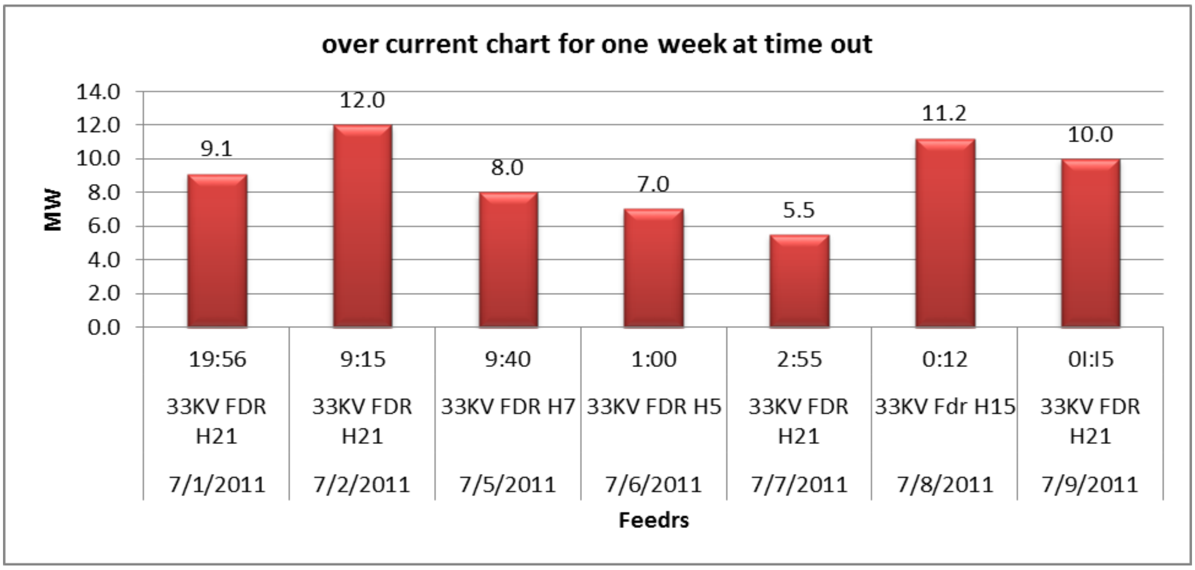

Fig 3: over current tripping of feeder for one week at time out.

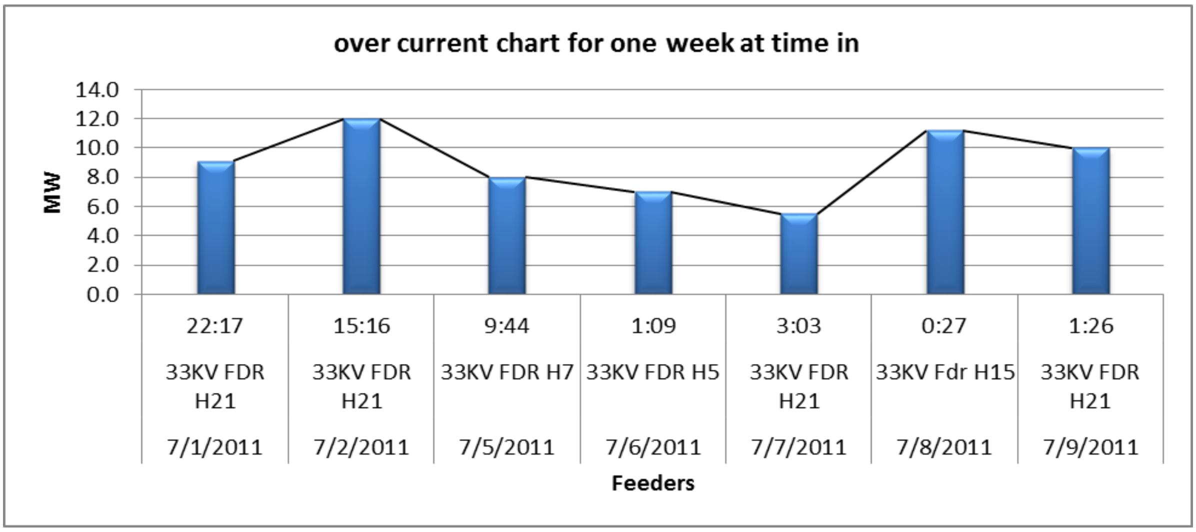

Fig 4: over current tripping of feeder for one week at time in.

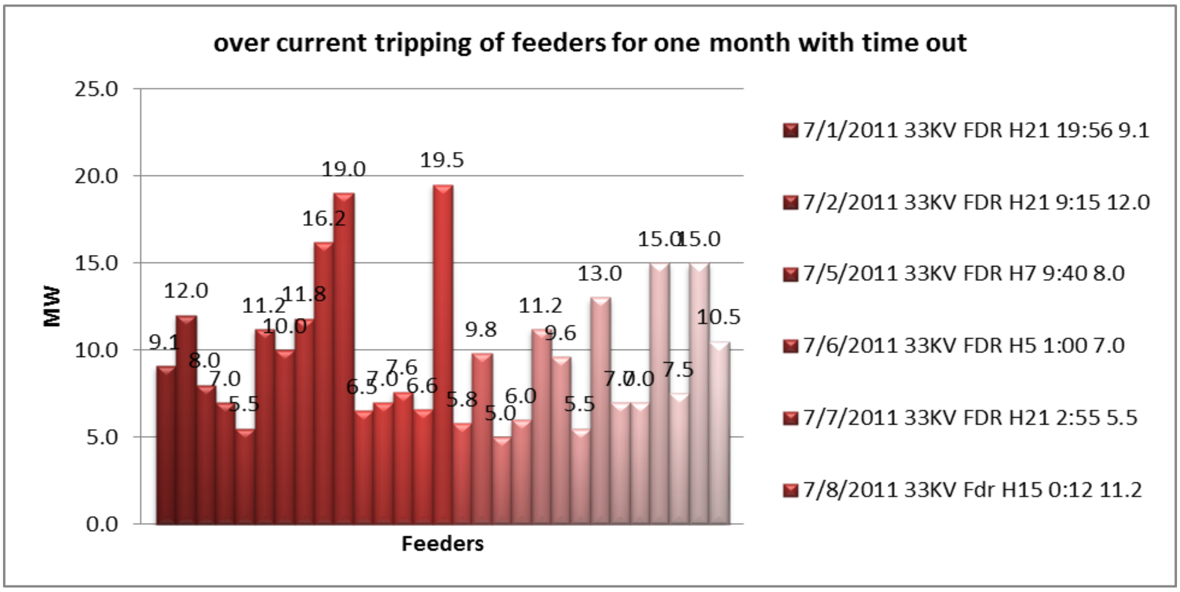

Fig 5: over current tripping of feeders for a month at time out.

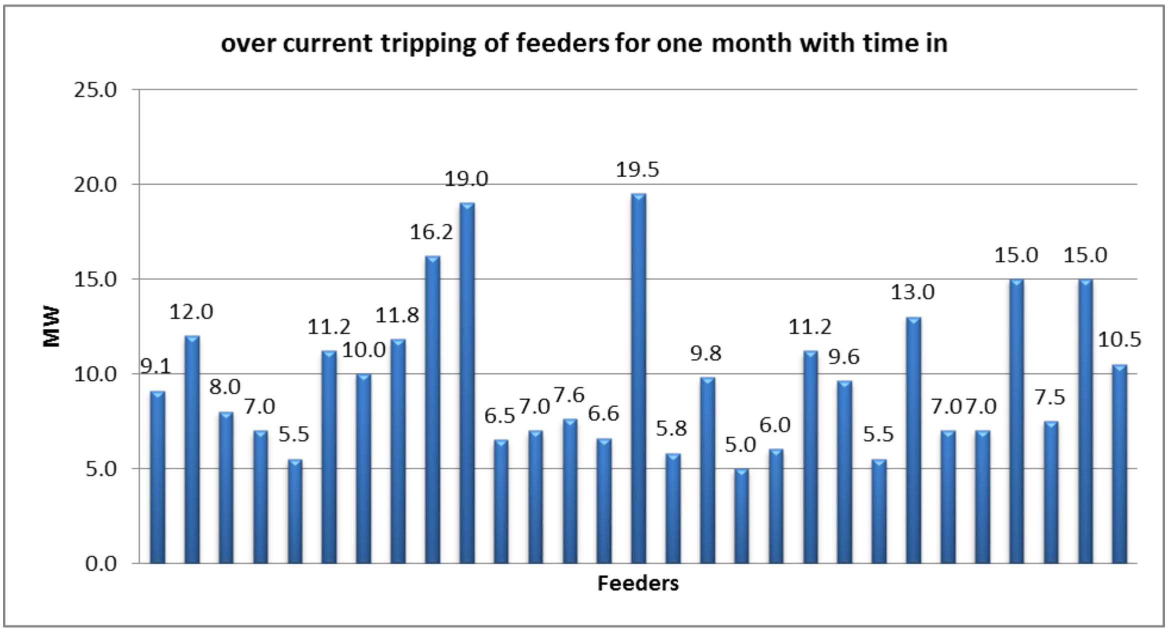

Fig 6: over current tripping of feeders for a month at time in.

LOAD CONSUMPTION

The figures 7, 8, 9, 10, 11 and 12 are the load consumption graphs for a day, with both time out and time in. Time out was the time of breaking of circuit breakers and the time in was or is the time at which the circuit breakers came back online for appropriate use for system protection.

In this case, the MW is plotted against the time, the dates and the feeders.as long as the feeders are on, business activities will go on at commercial areas or industrialized areas. If otherwise, the value of lost due to that time of outage will be much on the part of the customers. Feeders can also go down on over load and thereby affecting the system from being stable.

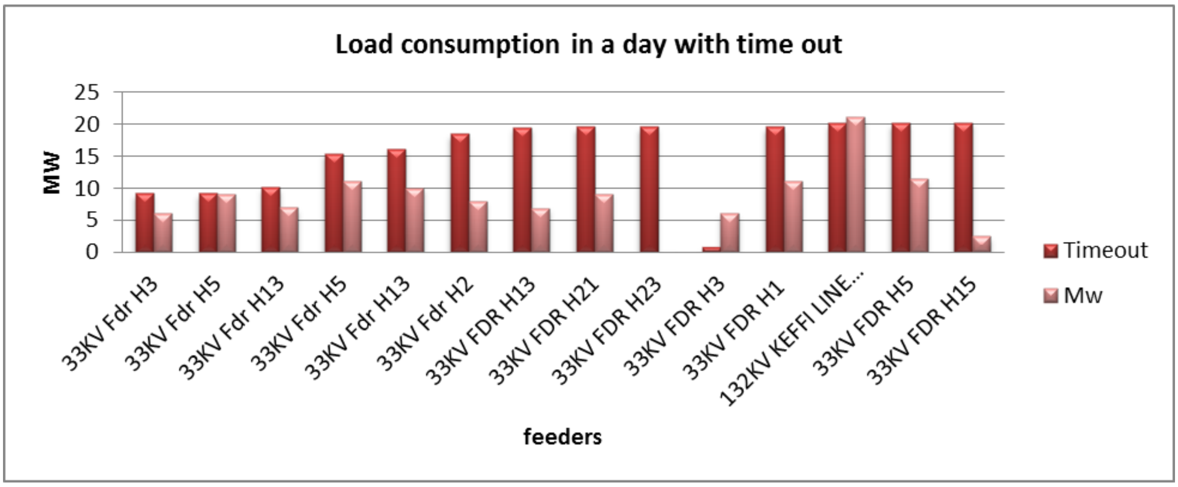

Fig 7: load consumption in a day at time out

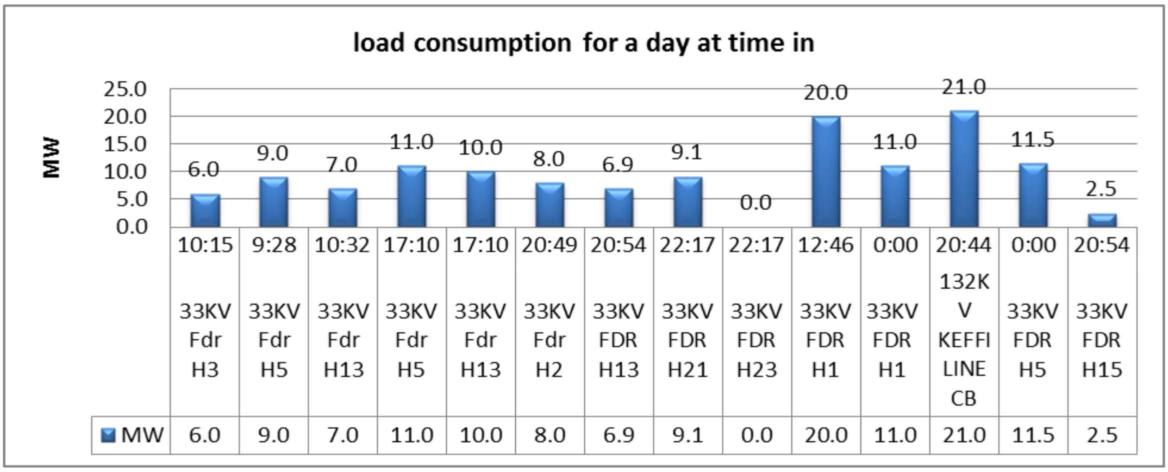

Fig 8: load consumption for a day at time in

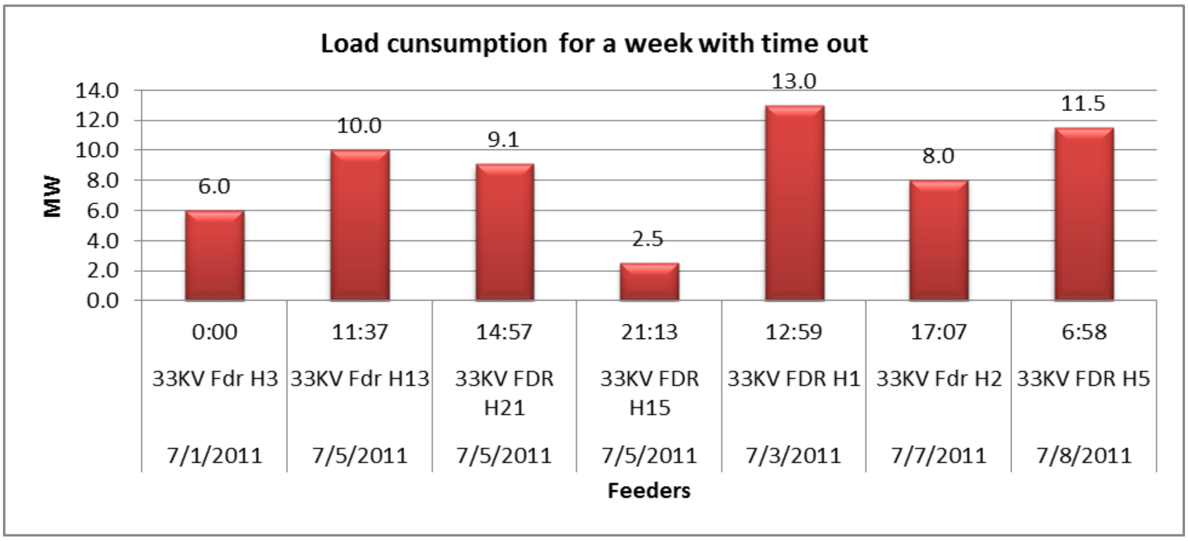

Fig 9: load consumption for a week at time out.

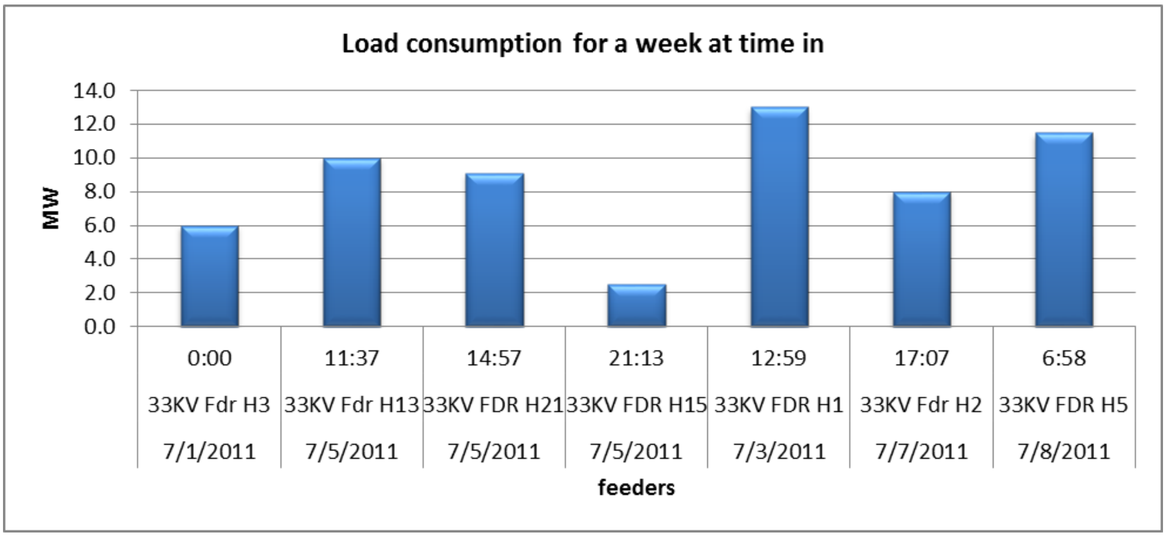

Fig 10: load consumption for a week at time in.

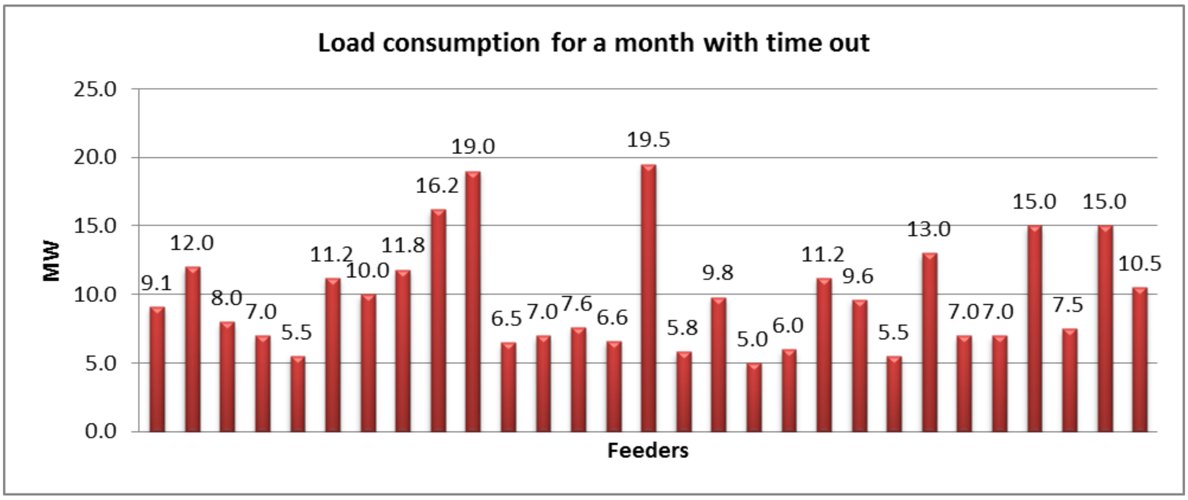

Fig 11: load consumption for a month at time out.

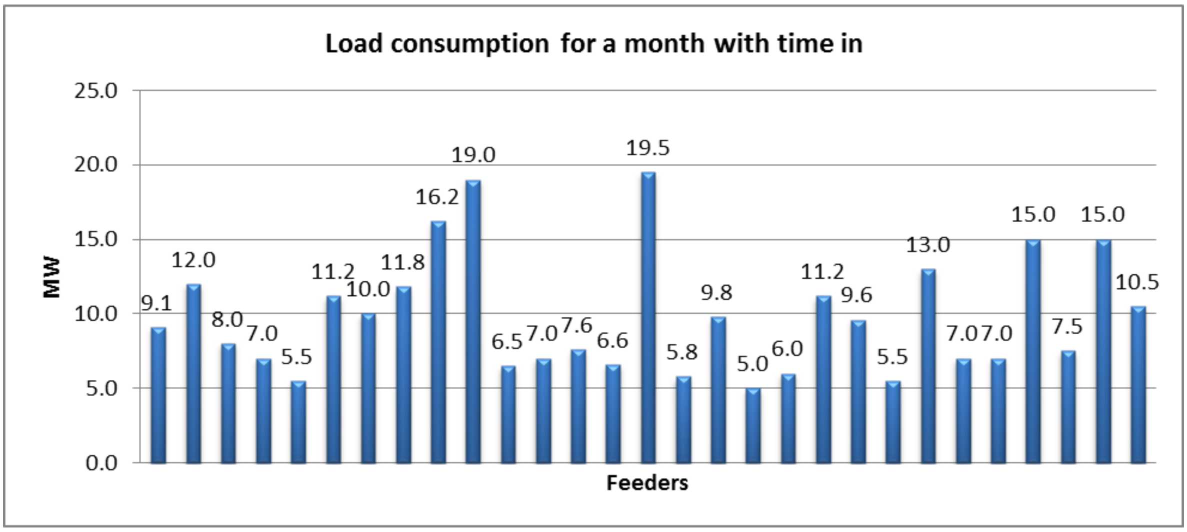

Fig 12: load consumption for a month at time in.

OUTAGE TIME OF FEEDERS

The figures 13, 14, 15, and 16 shows the outage time of feeders for a day, week, month and a year which could also cause a disadvantage in the part of the customers from being productive or affecting commercial activities in those industrialized areas following how the peak loads are on the graphs. It is also seen that those feeders that frequently tripping needs proper maintenance and routine maintenance culture should be employed.

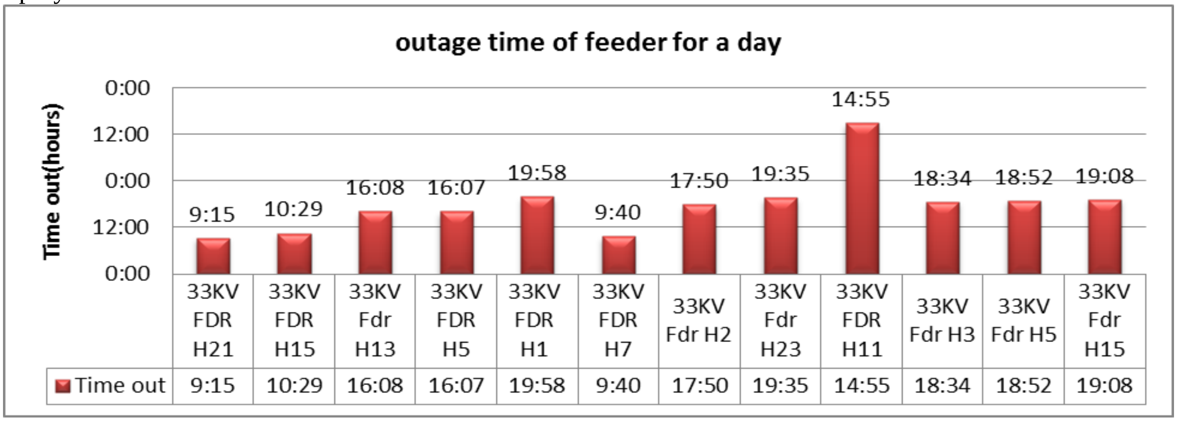

Fig 13: outage time of feeder for a day

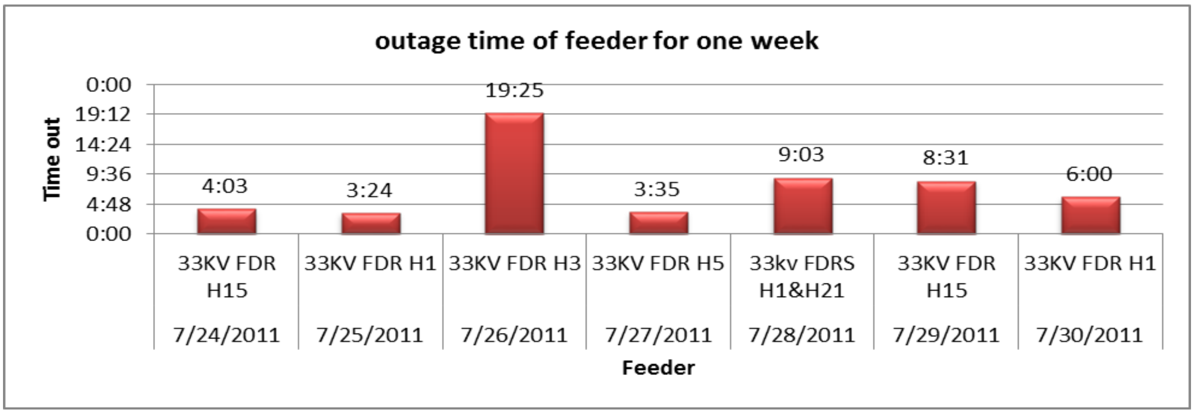

Fig 14: outage time of feeders for a week

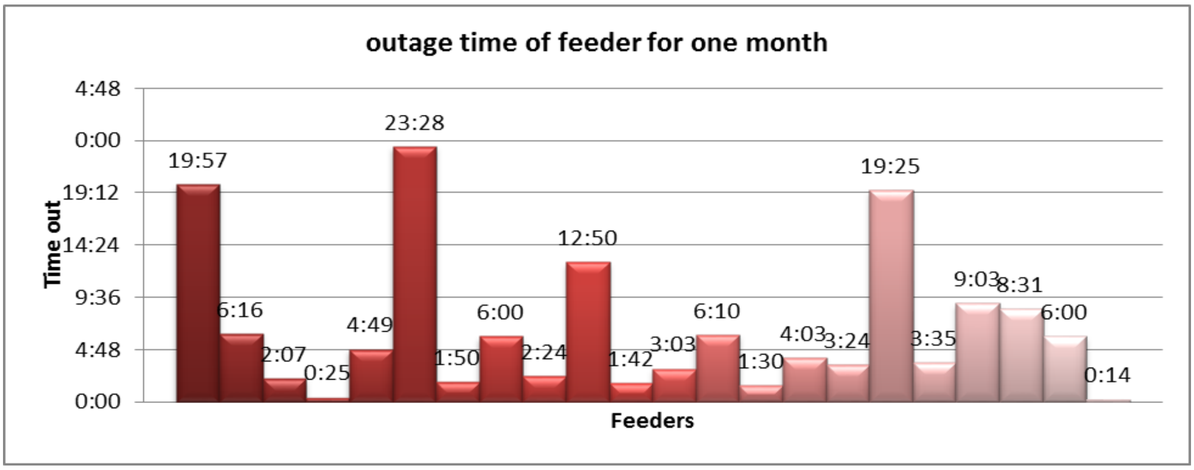

Fig 15: outage time of feeders for a month.

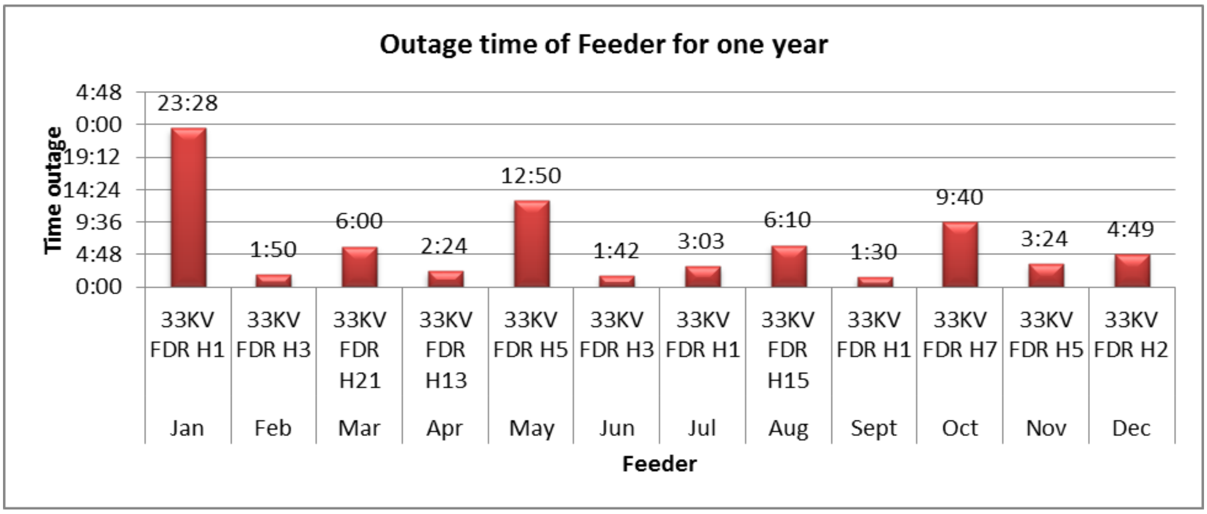

Fig 16: outage time of feeders for a year.

There are two aspects we should consider while dealing with over current, load consumption and outage time of feeders and these are the customers and the system itself.

All customers in the more condensed areas or commercial or industrialized areas at the time of outage went on blackout when the circuit breakers tripped on fault. That's to say commercial activities were affected as at that time of lost.

While on the part of the system, when load is lost due to fault and it has advantage which is, if the system was under pressure and lost that load the system will attain some form of stability and a disadvantage is that, if the system was more than 50Hz in terms of frequency, losing that kind of load will affect the system and if something is not done the machines can run on over speed and could cause machine collapse.

VIII. Conclusion

Circuit breakers are automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. They are preferred where continuity of service is an important consideration.

In order to avoid frequent fuse replacement, circuit breakers are appreciated and used because of their ability and capacity to interrupt just the faulted area and not the entire system. It shows that customers in the more condensed areas or commercial or industrialized areas at the time of outage went on blackout when the circuit breakers tripped on fault. That's to say commercial activities were affected as at that time of lost. While on the part of the system, when load is lost due to fault and it has advantage which is, if the system was under pressure and lost that load the system will attain some form of stability and a disadvantage is that, if the system was more than 50Hz in terms of frequency, losing that kind of load will affect the system and if something is not done the machines can run on over speed and could cause machine collapse.

IX. Recommendations

Routine testing of circuit breakers should be employed and to be tested in every six months interval for proper conditioning.

In every power system, there should be spare equipment standing-by for the one in use so as to help gain stability in the system.

To avoid wear and tear of system equipment, equipment should be alternated in terms of over usage.

Power supplied and power demanded should be at par to avoid over running of machines in terms of less demand because that could cause circuit breaker tripping.

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