Proposed Techniques for Identifying Open and Short Circuit Sections in Distribution Networks

Wael Al-Hasawi   Mahmoud Gilany

Electrical Technology Dept.,
College of Technological Studies,
P.O.Box 42325, Shuwaikh, Kuwait , 70654

KUWAIT

Wael_al_hasawi@hotmail.com   mahmoudgilany@ieee.org

Abstract:- This paper presents novel solutions for three problems encountered in the closed loop distribution systems. The first problem is how to identify a faulty section after being successfully isolated by the protection system. The second problem is how to identify a section affected with undetected open-circuit fault. A novel circuit is suggested in this paper to solve these two problems. The third problem addressed in the paper is how to deal with undetected faults in the 11 KV part of a 132/11 KV network which may result in a complete shut down problems. An effective modification in the trip circuit of the relays protecting the main feeders of the closed loops is suggested to avoid this problem. The validity of the proposed circuits is examined using ASPEN-OneLiner simulation program applied to a real part of Kuwait power distribution network. It is also checked against the specifications of the available equipment used in the real network. The proposed circuits provide fault detection capabilities normally achieved by the advanced and expensive Distribution Automation System (DAS) but with minimal cost.

Key-Words:-   Distribution networks, open-circuit faults, Undetected faults, Ring systems, Fault identification, Fault detection.

1 Introduction

Electric power systems are designed to ensure a reliable supply of energy with highest possible continuity. Fast determination of fault location is recommended for further fast repairing of the fault to restore the power.

Distribution systems being the largest portion of the whole network, diagnosis of faults becomes a challenging task. Faults in distribution systems affect power system reliability, security and quality.

Locating a fault in distribution networks represents a sophisticated problem since different locations of a fault can produce the same fault symptoms [1]. Accurate fault location minimizes the time needed to repair damage, restore power and reduce costs.

Fault location techniques in distribution system depend on the type of feeding (radial or ring) and the type of fault (short circuit or open circuit).

Regarding short circuit faults, and for feeders fed from one end, there are several fault location techniques in the literature [2,3,4]. Current and voltage signals at the relaying points are used in such techniques to estimate the distance to the fault.

This approach is not practical for two reasons. First, the voltage signals are not commonly used with most of distribution systems. Second, the error in the impedance estimated by the distance relays in such applications is usually large since the sequential feeders' types and/or sizes are not identical. The fault location techniques used with systems fed from two ends, or ring systems, are more complicated. Global Position Satellite (GPS) with synchronized data is one of these techniques [5].

In the last few decades, considerable amount of work has been done in the area of fault diagnosis particularly to the radial distribution system. The techniques used with systems fed from two ends or ring systems are very limited since the protection of such systems is more complicated [6].

Many standard techniques are based on algorithmic approaches but some latest techniques involve the use of Artificial Intelligent (AI) such as Artificial Neural Network (ANN). A brief review of some of the fault location techniques can be found in [7]. Most of the ANN based fault location techniques relied on the information about the status

of circuit breakers and relays. A brief comparison of various analytical techniques with ANN in transmission system fault location is provided in [8]. Artificial neural networks, when applied directly to fault diagnosis problem utilizing the time variation of fault current as input signal, suffer from the large CPU time required for the training and also dimensionality of the network. Hence, some preprocessing technique is required to reduce input data set.

The Wavelet Transform (WT) theory provides an effective way to examine the features of a signal at different frequency bands. These features may be essential for pattern recognition. Hence, it is well suited for the fault identification and classification in the power systems [9-11].

For open circuit fault detection, there are different techniques [12-14]. Most of these techniques are designed for overhead distribution networks. A prototype Ratio Ground Relay for the detection of broken conductor is developed in Pennsylvania Power and Light in USA. This relay depends on ratio setting between the zero sequence current components and the positive sequence current component [15].

There are also some Non Protective Devices used to detect the open conductor case like Kearny Manufacturing Company's Open Conductor Detection system (OCD). It uses the loss of voltage to detect downed conductor case. The system is only suitable for radial feeders. It depends on measuring voltage at the end of the feeder. If the voltage is lost then it sends a signal to the first upstream breaking devices to open the circuit if it has a voltage value [16].

A fault or a disturbance, which leads to high values of line currents, is generally detected by the protective devices and faulty section is isolated using re-closures and/or circuit breakers. However, the location of the fault and identification of the fault are normally not known unless you have a powerful fault location scheme which is not an easy task in distribution systems.

The system restoration can be expedited very fast if the location of fault is known or can be estimated to some accuracy. Hence, faults in a distribution system have to be detected instantaneously, irrespective of whether they are of permanent or temporary nature, to isolate only faulty section. Identifying the fault section, forming part of fault diagnosis aiming at minimizing the maintenance and repair time.

Considering the extensive size of the network, these tasks can be effectively achieved through implementing systems utilizing the available high-

speed computer and communication technology. The Institute of Electrical and Electronic Engineers (IEEE) has defined Distribution Automation System (DAS) as a system that enables an electric utility to remotely monitor, coordinate and operate distribution components, in a real-time mode from remote locations [17,18].

The DAS is based on an integrated technology, which involves collecting data and analyzing information to make control decisions, implementing the appropriate control decisions in the field, and also verifying that the desired result is achieved. The software acquires the system data (both static and dynamic) and converts it into an information system. The engineering analysis software provides the control decision utilizing the system information. The decision making feature of the distribution automation distinguishes it from the normal Supervisory Control and Data Acquisition (SCADA) system [19]. However, such systems may not be accepted because of its high expenses.

This paper takes part of the Kuwait distribution system as a case study. It deals with three practical problems related to closed loop distribution systems. The proposed technique is meant for any closed loop distribution system protected by differential protection.

The first two problems related to identifying the faulty section in case of detected short circuit faults and in case of undetected open circuit faults. A novel circuit is suggested in Sec. 4 in order to solve theses two problems.

The third problem addressed in the paper is related to the permanent undetected short-circuit fault in the 11 kV side which may result in a complete shut down of the 132/11 kV substations. An effective modification in the relays trip circuit is suggested to minimize the occurrence of such a problem and it is covered in Sec. 6 of this paper.

The problems studied are described by the electrical field engineers and are investigated using ASPEN-OneLiner simulation program, V9.7 [20]. This program is a PC-based short circuit and relay coordination program widely used by protection engineers. The performance of the proposed circuit is compared with the equivalent Distribution Automation System (DAS).

2. The Network Under Study

A typical 132/11 kV from Kuwait distribution network is shown in Fig. 1. It contains closed loops with different sizes. Every substation (represented with solid circle in the figure) contains three 1000

kVA transformers. The distances between the substations are shown on the drawing. The most left-hand side closed loop is taken as a case study. New added transformers to the original network – each rated 1000 kVA - are represented by empty circles.

In distribution systems where the distances between substations are short, differential protection is usually the preferred protection scheme. This is the case with studied case where the main feeders in the 132/11 kV network as well as the feeders supplying the 11/0.415 kV distribution transformers are all protected with differential relays.

2.1 Protective Schemes

As started above, differential protection is the applied protective system for every section of the network under study. Only the main feeders outgoing from the station are protected by overcurrent relays (F1, F2, and F3) in addition to the differential relays.

One of the most critical problems with such a scheme is the absence of backup feature. If the differential protection of any section (say the section between H33 and H75 in Fig. 1) failed to clear a fault, then the three main overcurrent relays and/or earth fault relays at F1, F2 and F3 (shown in Fig 1) will operate to clear the fault. It means that the full loop will be unnecessarily disconnected.

It may be thought that other protective schemes (e.g. directional overcurrent relays with proper coordination) may be more effective in such networks than differential relays. In fact, the directional overcurrent relays are not suitable with this network since they are affected by the large variation in loads during summer and winter seasons in Kuwait. The load varies from about 10250 MW in summer to 2800 MW in winter. Unless the settings of the relays are changed after each season, which is a time-consuming mission, the relays sensitivity may be badly affected.

Another time-consuming solution is to open all the closed loops in summer to avoid disconnecting the whole loop in case of a failure in the differential relays.
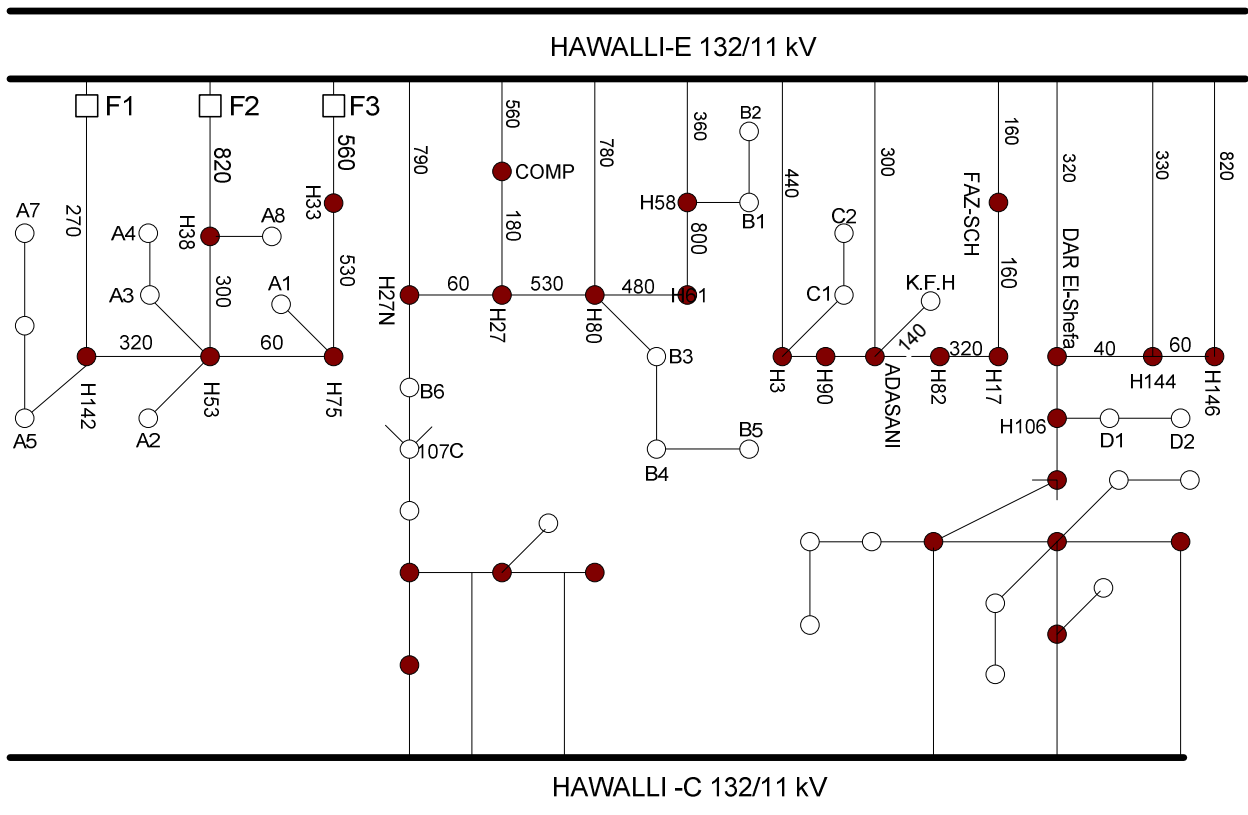

Fig. 1 A typical distribution network

As a result of these problems, the differential protection was the preferred protection system for such networks.

3. Addressed Problems

Typically, there are four possible faults scenarios in distribution systems:

1- Short-circuit fault, which is successfully detected and isolated by the feeder differential protection system. For this type of fault, the affected section is not directly identified. Note that the continuity of service will not be affected at any substation. That means no body sets alert to the maintenance team.

2- The second type is a permanent open-circuit fault which is not detected by any protection system (neither the differential protection nor the overcurrent relays in the main station) and hence its section is not also identified. Again, the continuity of service will not be affected at any substation.

3- The third type is a short-circuit fault which is neither detected by the feeder differential relay nor the main overcurrent relays but isolated by the station standby earth fault relay at the high voltage-side. This fault results in a complete shut down of the station.

4- The fourth type is a short-circuit fault which is not detected by the differential relay but isolated by the main overcurrent protection relays. The affected section is also not identified. This type of fault is not covered in this paper.

4. The Proposed Technique

In many existing distribution systems, faults are dealt with by manual intervention and rectified in a time consuming way such as sending a team of people to a predicted faulted area to investigate what has happened. It takes long time to solve the problem and a lot of costs involved in this process.

The previously mentioned problems may be easily identified if the network is provided with Distribution Automation System or SCADA system [21]. However, such systems may not be accepted because of its high expenses.

The proposed technique is meant for any closed loop distribution system protected by differential protection. Kuwait power distribution network is taken as a real example. It facilitates the automation of the network with very little added costs.

The key of the proposed circuits is to get use of the spare wires in the pilot cable associated with the differential relays protecting the loop's feeders in order to transmit certain information (status of the circuit breaker and the relay of the affected section) to a PLC unit in the main 132/11 kV station. Usually, the pilot wire consists of about 16 pair of wires. In many cases, only one or two pairs are used where the others are spare.

The PLC unit processes the received information and sends SMS message through a *modem* to a *GSM cell phone*. The phone The data included in this message informs the maintenance team about the faulty section. The exact fault location within the identified affected section is determined later - off line- using any of the common used cable tracers.

4.1 Implementation of the Circuit

The input of the PLC for the studied network consists of eight analog inputs carries information from a limited numbers of the loop's CBs and its associated relays.

Only the auxiliary output-contacts of *four* circuit breakers (and the associated *four* relays) represented with solid rectangular in Fig. 2 are involved in the proposed circuit. The eight input signals are: status of four "Normally-Close" output-contacts from the CBs (represented with solid rectangular in Fig. 2) plus status of four auxiliary "Normally-open" output-contacts of its associated relays.

The Normally-close auxiliary output contact of any circuit breaker will become "close" only if the circuit breaker's status becomes "open". On the other hand, the auxiliary (NO) output of the relay – which is controlled by the relay algorithm – will become "closed" only if the current through the protected feeder drops to zero *provided that the CB contacts are still closed.*

The last condition is necessary to differentiate between the zero current resulting from a normal feeder opening and the zero current resulting from undetected open circuit fault.

4. Locating a Detected Short-Circuit Fault

In this case, we assume that there is a short circuit fault which is detected and isolated by the differential protection. The faulty section in this case will be opened from both sides after clearing the fault.

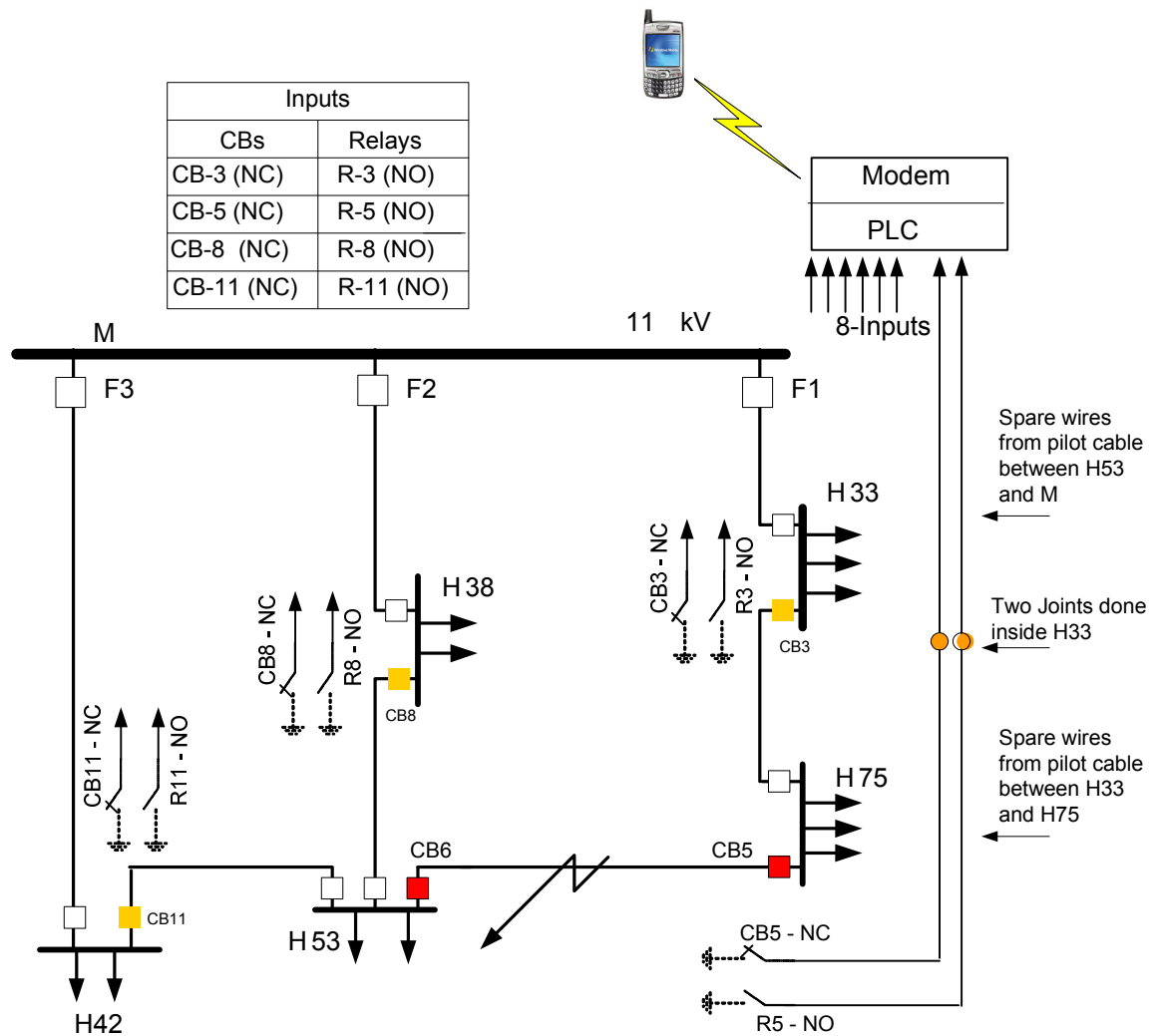| Inputs	
CBs	Relays
CB-3 (NC)	R-3 (NO)
CB-5 (NC)	R-5 (NO)
CB-8 (NC)	R-8 (NO)
CB-11 (NC)	R-11 (NO)

Fig. 2: Implementation of the proposed circuit.

For example, for the fault occurred in the section between substations H75 and H53 as shown in Fig. 2, the differential protection system detects this fault and isolates the affected feeder. The two circuit breakers: CB5 and CB6 will then be opened after clearing the fault.

The costumers will not be affected by opening the faulty feeder since the system is originally fed from more than one point. The problem is that the utility maintenance teams will not also feel that there is a fault that has occurred and cleared in that loop or in that section. The only available information which may be useful to attract the attention of the maintenance team to that loop is the disturbance in current distribution in the three main feeders (protected by F1, F2 and F3) shown in Fig.

2. These currents are monitored by the supreme control center.

The maintenance team usually depends on this sole information – current disturbance - to predict the location of affected loop and the opened feeder. In many cases, this variation in the current distribution doesn't give a clear indication about the affected loop or the affected section. The maintenance teams in many cases have to search for it from a substation to another.

In the proposed circuit, the status of the "normally-closed auxiliary contact" of the selected CBs is transmitted to the PLC unit at the substation through the spare wires of the pilot cables. For example, the status of the auxiliary contact of CB5 (see Fig. 2) is transmitted to the main station M using spare wires of two pilot cables: a spare pair

from the cable between "H75 and H33" and then the spare cable between "H33 and the main station, M". Only a junction between the two spare wires is required to be added to facilitate this operation.

Once a fault is cleared, the status of the NC auxiliary contact of CB5 will be changed from "open" to "close". One input to the PLC is then changed. The new situation is processed and consequently, SMS message will be forwarded to a certain cell phone-number stored in the PLC program. The maintenance team is easily informed about the cleared fault and hence the faulty section is identified. Any other detected short circuit fault is identified in a similar way.

One alternative method for identifying the faulty section needs an RTU in each point in the loop plus an efficient communication network between all the load points. Other alternative techniques which depend on calculating the fault distance are not easily implemented with closed loop systems.

The main feature of the proposed technique is to instantaneously identify the faulty section – like DAS or SCADA - but with minimum additional cost added to the existing system (the cost of only one PLC unit per substation). It saves a lot of time and efforts.

5. Locating an Undetected Open-Circuit Fault

Open conductor (downed conductors) from the point of view of distribution utility is a public hazard in the main consideration. It is not a system operation problem since the system could continue without disconnecting such fault [22].

The second fault scenario studied in this paper is to have an undetected open circuit fault. This may happen as a result of a cut in the power cable. In this case, the power cable (and may be the pilot cable as well) is opened but the circuit breakers of the faulty section - at both sides - are kept closed.

The only available indication showing that there is a problem is the disturbance in currents distribution in the three main branches of that loop (F1, F2 and F3 in Fig. 2). However, this information is not guaranteed as the variation in the currents may be very small. It is not always easy to identify the affected section based on these current readings. Again, even if we got information about the disturbance in certain loop, this information can't tell us about the faulty section in the affected loop specifically.

The maintenance crew has to go through the stations to check the status of the breakers.

Inspecting the location of faults is done with manual intervention and are rectified in a time consuming way. For some faults, it takes a long time and a lot of costs to solve the problem.

With the proposed circuit under such condition, the PLC unit will receive a signal from the NO auxiliary contact of the relay associated with the faulty section once the current in that section drops to zero and provided that the status of the CBs is not changed. The case is then identified as "undetected open-circuit fault" in that specific section.

For example, if undetected open circuit fault is assumed on the section between stations H38 and H53, then the NC auxiliary contact of CB-8 will be kept "open" since the main poles of the CB is still closed while the auxiliary NO contact of relay R8 will be changed to "close" status. The PLC will process this new information and decide the faulty section before directing a message through the modem to the responsible person.

6. Avoiding Unnecessary Complete Shutdown

The third problem addressed in the paper is to have a permanent short circuit fault which is not detected by any of the protection systems in the low-voltage side (neither differential nor overcurrent protection).

However, it is isolated by the transformer standby-earth fault relay located at the high voltage side. In this case, not only the faulty loop will totally be disconnected but also all the other healthy loops supplied from the same bus bar at the substation (complete shut down).

There several reasons for such a problem. In some cases, there is a poor discrimination between the 132/11 kV transformer primary overcurrent relay and overcurrent relays protecting the outgoing feeders. A typical case is shown in Fig. 3.

The differential protection can't detect such a fault as it occurs directly on the bus-bars of substation H53. The phase overcurrent protection (OP's) for the three main feeders will all trip to isolate the fault.

It can be seen from Fig. 3 that there is a very short time gap between the transformer primary OC relay operation time (OP 2.71 Sec) and the relay F3 (OP 2.69 Sec.). There is a degree of uncertainty in knowing which one will trip first. In many cases, both operate at the same time. This coordination problem is one of the reasons that lead to unnecessary complete shutdown of the station.

In other cases, especially with a single line to ground fault, there is a probability that one of the

three overcurrent relays (F1, F2 and F3) may fail to detect the fault as per the case shown in Fig. 4. The fault location is assumed between stations H38 and H53. Under such condition, the relatively long distance between the fault point and relay F1 may be the reason for such a failure.

The problem is also expected if the fault occurred while only two of the three 132/11 kV transformers are in service (low in-feed) or if the fault occurred through a fault-resistance as per the case shown in Fig. 5.
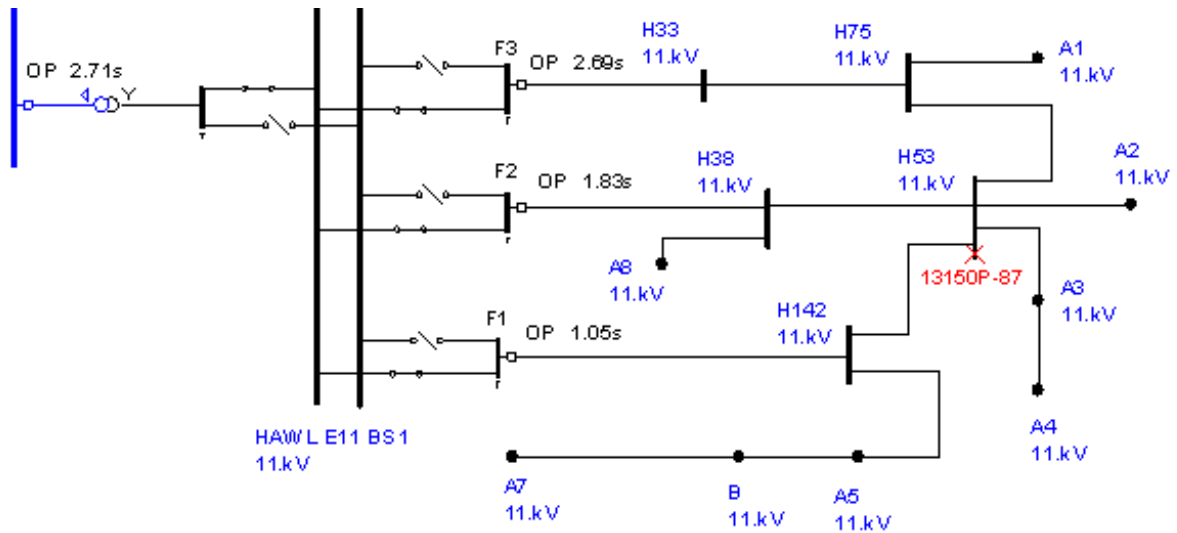
Fig. 3: Three line to ground fault at Bus-bar H53.
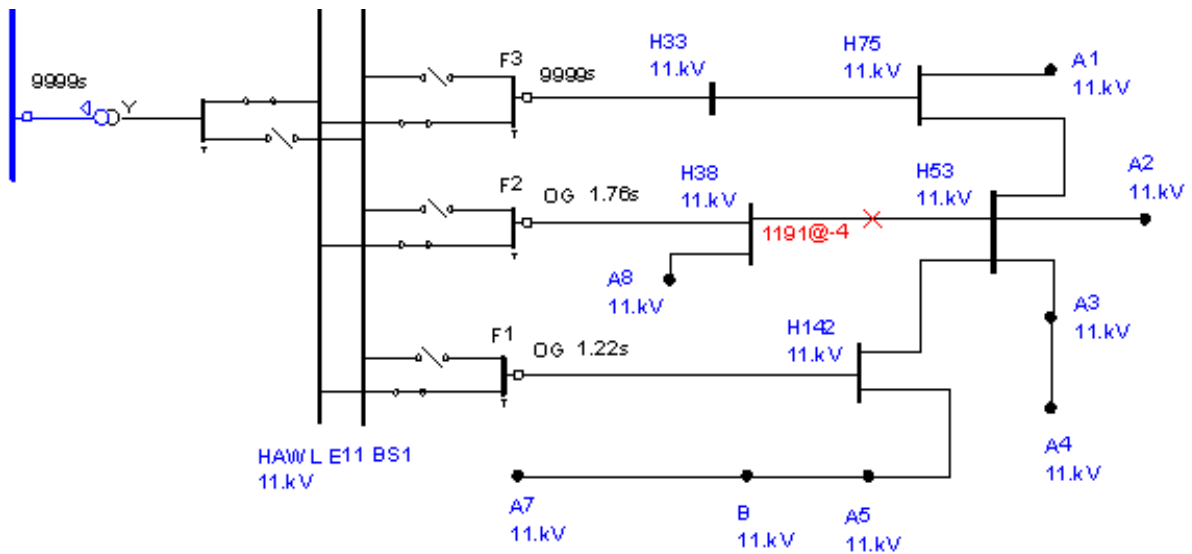
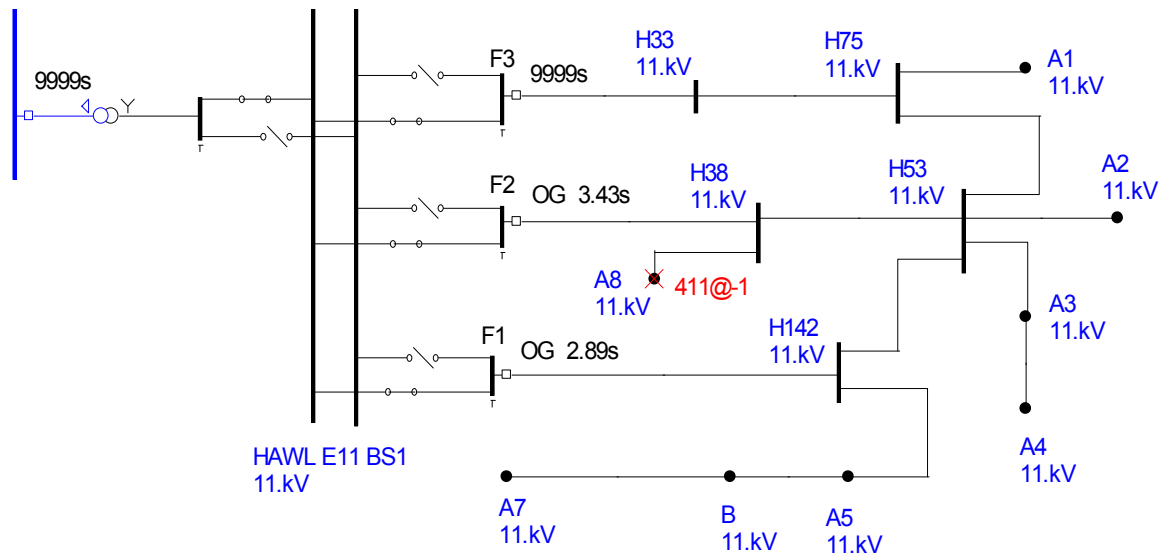

Fig. 4: SLG fault between H38 and H53

Fig. 5: SLG fault through 10-Ω resistance.

This fault occurred through a 10 ohms resistor. The fault current level is severely reduced such that only two of the three ground overcurrent relays (OG's) detect it.

It can be seen from Fig. 4 and Fig. 5 that only the two relays F1 and F2 trip successfully while the third relay F3 does not detect the fault. Consequently, the fault current will find a path to the fault point even after disconnecting the other two relays.

If this fault persists for long time, the transformer standby earth fault protection, installed in the transformer neutral connection, will trip the main transformer.

6.1 Modifications to Trip Circuit

Usually, all the three 132/11 kV transformers are connected in parallel with common standby earth fault relay as shown in Fig. 6. It means that the station will be completely shut down if that EF relay operates.

The principle of the proposed solution is based on the fact that if a fault in any section is detected by the corresponding differential relay, then none of the overcurrent relays R1, R2 and R3 (see Fig 7) will operate. On the other hand, closing the contacts

of any of the three overcurrent relays (R1 or R2 or R3) means that the differential relay for a certain section failed to operate.
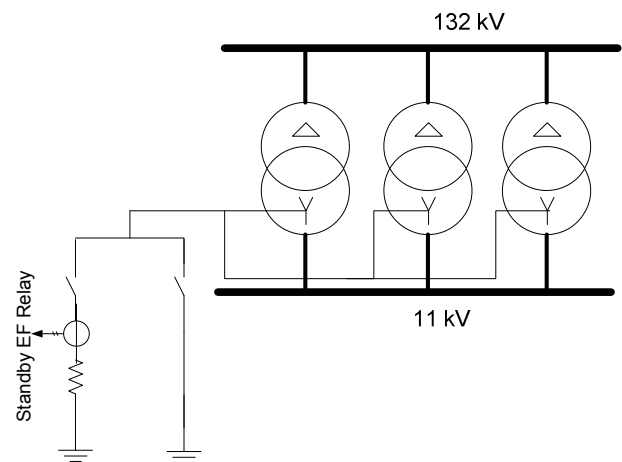

Fig. 6: Common Earth Fault Protection

The idea of the modified circuit is to accelerate the trip of the other two loop breakers as soon as a fault is detected by any one of the three OC relays.

The three CBs will trip simultaneously once any relay contacts is closed as shown in Fig. 7. This will partially prevent the condition of feeding a fault from un-tripped feeder and consequently avoid the complete shutdown.

This idea is very useful especially if the fault occurred at newly added transformers which are shown in Fig. 1 as empty circles. Under such conditions, there is a high probability that at least one of the main relays may fail to detect the fault as a result of low fault current level.
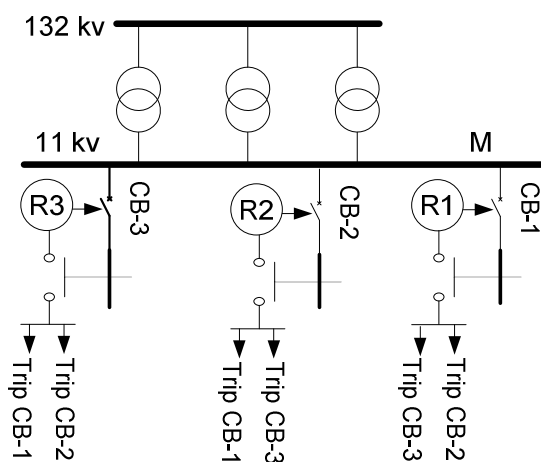

Fig. 7: The modified trip circuit.

7. Conclusions

This paper presents a practical field experience with Kuwait distribution networks. Novel circuits for identifying the faulty section in case of detected short circuit fault and undetected open-circuit fault are presented. Another circuit is presented to avoid the problem of shut down of the whole 132/11 KV station. The proposed-circuits reduced technical and commercial losses, lower electric service restoration time, reduce the equipment damage, and enhanced power quality and reliability. These circuits succeeded to fulfill many tasks of DAS systems with minimum cost since it saves the cost of communication network and the cost of the RTUs required at each load point.

8. Acknowledgments

9. References

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