Proposed Techniques for Identifying Faulty Sections in Closed-Loop Distribution Networks

Wael Al-Hasawi Mahmoud Gilany

College of Technological Studies,
Electrical Technology Dept.,

Kuwait

Abstract— This paper deals with three problems in closed loop distribution systems. The first problem is how to detect and identify the faulty section after a *short-circuit fault* is 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 this paper is the *undetected short-circuit fault* which may lead to a complete shut down of the substation. An effective modification in the trip circuits of the relays protecting the main feeders of the closed loop is suggested to minimize the occurrence of this problem. The validity of the proposed circuits is checked against the specifications of the available equipment used in the network.

Index Terms-- Distribution networks, open-circuit faults, Fault identification, fault detection.

I. Introduction

Distribution systems being the largest portion of the whole network, diagnosis of faults becomes a challenging task. Faults in distribution systems effect power system reliability, security and quality. Accurate fault location minimizes the time needed to repair damage, restore power and reduce costs. The application of traditional fault location techniques that use fundamental voltages and currents at line terminals for distribution lines with tapped loads is difficult [1].

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.

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.

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 [2].

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 [3]. 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 [4]. 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 [5-6].

For open circuit fault detection, there are different techniques. Most of these techniques are designed for overhead distribution networks. One of the algorithms used to detect open conductor is the technique developed by Lee and Bishop from Pennsylvania Power and Light (PP&L) in USA [7]. They developed a prototype Ratio Ground Relay for the detection of broken conductors. This relay depends on the ratio setting between the zero sequence current components and the positive sequence current component.

Another algorithm is developed to identify and locate downed conductor fault case by monitoring the voltage unbalance along the distribution feeder. As the system measures the unbalance voltage at various points so it could give indication of the fault place [8].

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 [9]. 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 [10]. 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 types of problems related to closed loop distribution systems.

Two problems are investigated in Section III. The first problem is how to identify successfully the faulty section after a short-circuit fault is successfully detected and isolated by the differential protection system. Under such condition, the affected section is not easily identified. The second problem is related to permanent open-circuit fault which is not detected by any protection system and hence its section is not also identified. A novel circuit is suggested in section III in order to solve these two problems.

The third problem addressed in the paper is related to the permanent short-circuit fault which is not detected by neither the differential relay nor the overcurrent relay, but isolated by the earth fault relay of the high voltage-side. Such a fault results in a complete shut down of the substation. An effective modification in the relays trip circuit is suggested to minimize the occurrence of such a problem and it is covered in section IV of this paper.

The performance of the proposed circuit is compared with the equivalent Distribution Automation System (DAS). The proposed circuit proves a similar performance as DAS with minimum cost.

The problems studied are described by the electrical field engineers and are investigated using ASPEN-OneLiner simulation program, V9.7 [11]. ASPEN OneLiner is a PC-based short circuit and relay coordination program widely used by protection engineers.

II. 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 right-hand side closed loop is taken as a case study. Differential protection is the applied protective system for every section of the loop. Only the main feeders (F1, F2, and F3) outgoing from the station are protected by additional overcurrent relays.

III. Identifying a Faulty Section

The objective of this part of the paper is to fast identifying the faulty section – in a similar way like DAS – but with a minimum cost system. The key of the proposed circuits is to get use of the spare wires of the pilot cable - associated with the differential relays - to transmit certain information related to the affected section to a PLC (Programmable Logic Controller) 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 input of the PLC for the studied network consists of eight analog inputs. Information from a limited numbers of the loop's CBs (and associated relays) are required. Only the auxiliary output-contacts of the circuit breakers (and its associated relays) represented with solid rectangular in Fig. 2 are needed in the proposed circuit. The eight input signals are: four "Normally-Close" (NC) output contacts from the CBs represented with solid rectangular plus four auxiliary "Normally-open" (NO) output contacts of its associated relays.

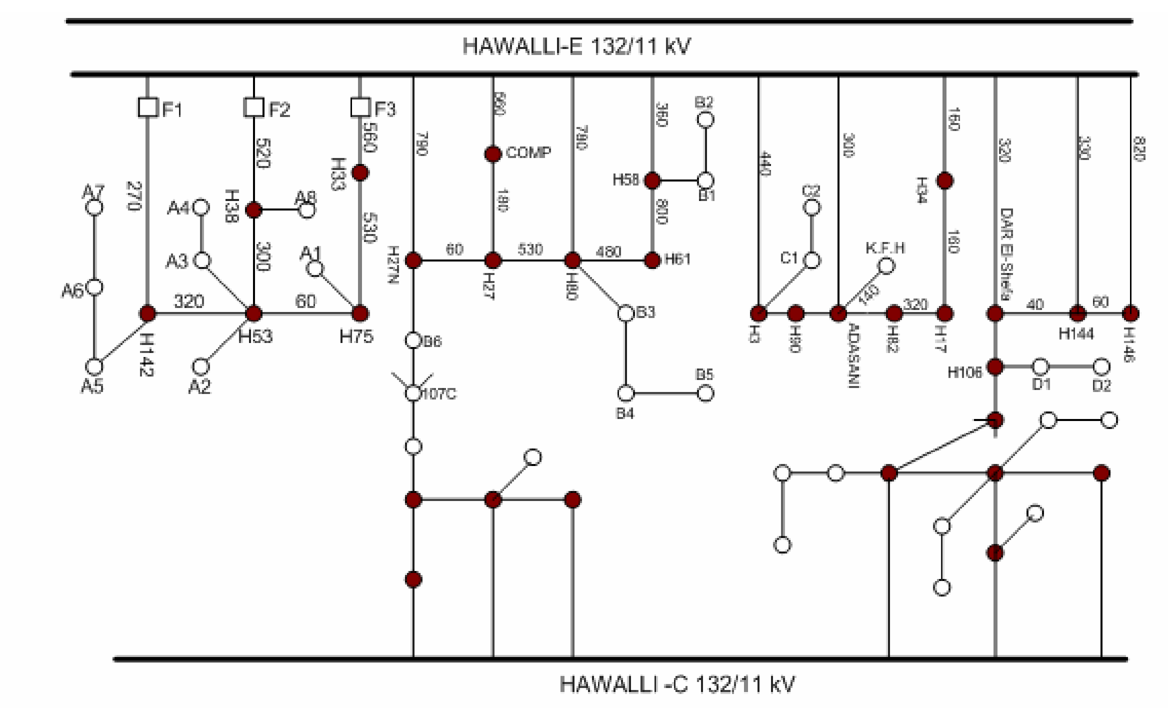

Fig. 1 A typical Distribution Network

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.

The PLC unit processes the received information and sends SMS message through a modem to a GSM cell 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.

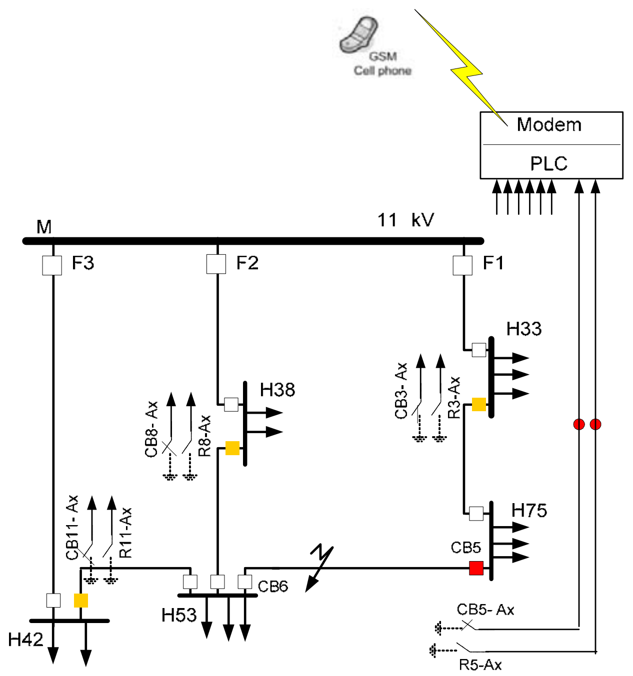

Fig. 2: Identifying an open circuit section from both sides

A. 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. 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 (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 neither the affected loop nor 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". 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.

An 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 this technique is to instantaneously identify the faulty section – like DAS - 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.

B. 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 [12,13].

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".

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" while the auxiliary NO contact of relay-8 will be changed to "close" status.

IV. 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) but 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 (2.71 sec) and the relay of feeder FD1 (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 some 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. This case is also expected if the fault occurred while only two of the three 132/11 kV transformers are in service or if the fault occurred through a fault resistance. Under such conditions, the sensitivity of the relay will be reduced. 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.

Usually, all the three 132/11 kV transformers are connected in parallel with common standby earth fault relay. It means that the station will be completely shut down under such conditions.

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 4) 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.

The idea of the proposed solution 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. 4. This will partially prevent the condition of feeding a fault from un-tripped feeder and consequently avoid the complete shutdown.

V. 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 almost neglected cost since it saves the cost of communication network and the cost of the RTUs required at each load point.

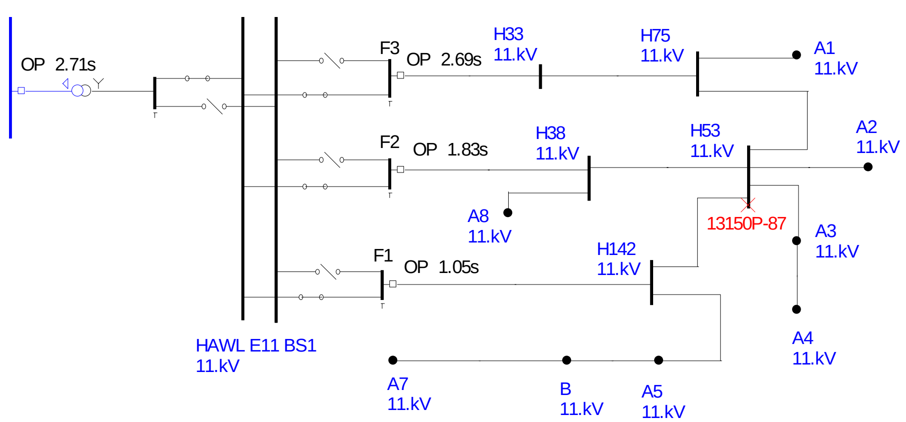

Fig. 3: Three line to ground fault at Bus-bar H53.

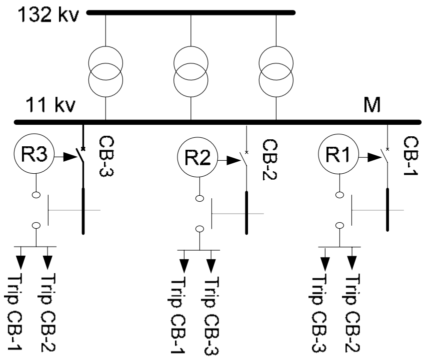

Fig. 4: The modified trip circuit

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