Design and Performance Analysis of a Bus-Bar Transmission System Protection Scheme Using MATLAB/SIMULINK

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Abstract: - Protective systems form an important part of all electric power networks, making it of major importance to study the performance of these systems. This paper deals with the design and simulation of a bus bar protection scheme using MATLAB/SIMULINK for a 132 kV section of the Karbala transmission network, which is used as a case study for the paper. A performance analysis of a three phase to ground fault is analysed within the simulated system, in which a differential relay is used as the main protection element and an overcurrent relay is used as backup protection.

1. Introduction

Electric power network protection criteria are adopted on the bases that the network must be divided into overlapping zones to ensure multiple protective systems apply to each part of the network [1][2]. Generally, these systems are referred to as main and back up protective systems.

Due to its importance, an electrical power system must be protected adequately to save human lives and money. Each piece of equipment in the various systems must thus be kept in isolation during any failure; such quarantine systems are generally the main protection systems used to isolate faulty equipment, while backup protection systems operate if the main protection system fails [3][4].

A bus is one of the most critical system elements, bring the connecting point of a variety of elements and a number of transmission lines; thus, any incorrect operation in the bus could cause the loss of multiple elements. Protection of bus-bars demands high speed reliability and stability, and failure-to-trip on an internal fault, or false tripping of a bus-bar during service or in the case of an external fault, could have disastrous effects on the stability of the power system, possibly causing complete blackout. Designing a bus-bar protection scheme thus requires precision and reliability [5].

Bus bars, as part of the power network, are generally protected by differential main protection, and overcurrent backup protective schemes [6][7].

2. Overview of Karbala 132 kV Transmission Network System:

Karbala city transmission network, as shown in Figure 1, is connected to the Iraqi power grid at three stations, Babylon (400/132/11 kV), Mussayab (400/132/11 kV), and Khairat (400/132/11 kV). The Karbala transmission network consists of eleven substations as follows:
- Five generation buses (1), (2), (3), (4), (5)
- Six load buses [(6), (7), (8), (9), (10), (11)]
- These substations connected are by twelve transmission lines, as shown in Figure 1.
- Bus and line details are given in Tables 1 and 2 in Appendix A.
3. Design Methodology for a Bus-bar Protective Scheme foe 132 kV Karbala Network

The protection system for the bus bar consists of two subsystems, the main (or primary) protection system, with a differential relay, and a backup protection system with an overcurrent relay.
3.1 Differential Relay Simulation

Under normal conditions, the current \( I_p \) entering the protected unit is equal to the current leaving it at each instant. Considering current transformer A, the secondary current in the pilot wire is equal to [8][9]

\[
I_{AS} = a_A I_p - I_{Ae}
\]  

where

\( a_A \) is the transformation ratio of current transformer A

\( I_{Ae} \) is the excitation current of current transformer A in the secondary.

For current transformer B, the equation is similar:

\[
I_{BS} = a_B I_p - I_{Be}
\]  

where

\( a_B \) is the transformation ratio of current transformer B

\( I_{Be} \) is the excitation current of current transformer B in the secondary

Assuming equal transformation ratios, \( a_A = a_B = a \), the relay operation current \( I_{op} \) is given by

\[
I_{op} = I_{Ae} - I_{Be}
\]  

During normal system operation and external faults, the relay operating current, \( I_{op} \), is thus consistently small, but never zero.

Adopting the principles of operation explained and applying equations (1) to (3), the differential relay was simulated using MATLAB/SIMULINK as shown in Figure 3:

![Figure 3. MATLAB Simulation of differential relay](image)

3.2 Overcurrent Relay Simulation

In this system, an instantaneous overcurrent relay is used as a backup protection system. The relay was designed to operate and trip the circuit breaker for all currents above the chosen setting [7]. The level above which the relay operates is known as the pickup setting; for all currents above the pickup, the relay operates, while for currents smaller than the pickup value, the relay takes no action [7][10]. The MATLAB simulation of overcurrent relay is presented in Figure 4:
4. Simulation Results

Figure 5 shows the bus bar protection system created using MATLAB/SIMULINK for substation number 9 (East Karbala substation) of the Karbala transmission network, which is a PQ bus as shown in Table A.1.

This substation is primarily protected by a distance relay reliant on the transmission lines connected to it, and this cause problems in case of a bus bar fault.
If the fault occurs near the bus bar, the primary protection with differential relay must operate; if it fails to take an action, the backup protection system with overcurrent relay must detect the fault and use the circuit breakers (1 and 2) to isolate the disturbance.

A three-phase fault was applied to the system near the East Karbala bus bar of time duration 0.2 to 0.3 sec. The behaviour of the bus bar protection system during the fault duration is shown in Figures 6 and 7.

**Figure 5.** Bus bar protection system for East Karbala substation using MATLAB/SIMULINK
Figure 6. Protection system relays signals for a fault near the bus-bar

Figure 7. Protection system trip signals for fault near bus-bar adopting microcomputer
From Figure 6 above, it is clear that, during the fault, the two relays (differential and overcurrent) detect the fault and a trip signal is given to the system from the main protection (differential relay) as shown in Figure 7; this operation is controlled with the help of a microcomputer.

The circuit breakers used in the modelling are normally closed (the contact is closed when energised by receiving a 1 (ON state) and open when it receives a 0 (OFF state)). The CTs used have a ratio of 1200/5 A.

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Figure 8. Bus voltage and current before, during, and after a fault.

From Figure 8, during the period 0 to 0.2 sec., the system is seen working normally, while the period 0.2 to 0.3 sec., which represents the fault duration, shows the protection system isolating the bus bar from the transmission network. The period 0.3 to 1.0 sec. represents bus operation returning to normal after the circuit breakers reclose and the fault is isolated.
Figure 9. Protection system relay signals for a fault near the bus-bar and differential relay failure

Figure 10. Bus-Bar protection system trip signals during fault near the bus-bar and differential relay failure

Figures 9 and 10 above show the behaviour of the protection system when a failure happens in the differential relay. These make it clear that the overcurrent relay (the backup protection system) detects the fault and isolates it where the main protection system fails. Where this fails to detect the fault, backup2 (the protection system of the transmission lines connected to the bus-bar) detects and isolates the fault with the aid of the microcomputer that regularises the trip signals.
From the results, in particular referring to Figure 2 above, if the bus bar is protected by the proposed protection system presented above and a fault occurs at the bus-bar, the fault can be isolated by isolating the faulty bus only by opening the contacts of circuit breakers 1, 2, and 3, while in the case of the protection system currently used for the East Karbala bus-bar, if a fault occurs at the bus-bar, all transmission lines connected to the faulty bus must be isolated in addition to the faulty bus in order to isolate the fault, causing the loss of many healthy parts of the system.

5. Conclusions

A section of East Karbala 132 kV network was taken as a case study and a differential bus bar protection and overcurrent system designed and simulated in MATLAB to study fault effects on the Bus system.

The proposed protection system increases the reliability and dependability of the system by protecting the bus-bar when a fault occurs near it, and by isolating the faulty bus only, allowing non-affected lines to remain in the system, thus decreasing the number of elements taken out of the system during fault occurrence.

6. References

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Appendix A

Table (A.1). Karbala 132KV bus data

| Bus no. | Bus Name          | Bus Type | V(pu) | δ   | Pg (Mw) | Qg (Mw) | PL (Mw) | QL (Mw) |
|---------|-------------------|----------|-------|-----|---------|---------|---------|---------|
| 1       | Mussayab         | Slack    | 1.0   | 0   | 0       | 0       | 0       | 0       |
| 2       | Babylon          | PV       | 1.0   | 0   | 135     | 65.383  | 0       | 0       |
| 3       | Alghazia         | PV       | 1.0   | 0   | 96.3    | 46.545  | 0       | 0       |
| 4       | Khairat          | PV       | 1.0   | 0   | 135     | 65.383  | 0       | 0       |
| 5       | STX              | PV       | 1.0   | 0   | 99      | 47.85   | 0       | 0       |
| 6       | West of Karbala  | PQ       | 1.0   | 0   | 0       | 0       | 154     | 74.585  |
| 7       | Hindia           | PQ       | 1.0   | 0   | 0       | 0       | 198.5   | 96.137  |
| 8       | South of Karbala | PQ       | 1.0   | 0   | 0       | 0       | 164     | 79.428  |
| 9       | East of Karbala  | PQ       | 1.0   | 0   | 0       | 0       | 123     | 59.571  |
| 10      | North of Karbala | PQ       | 1.0   | 0   | 0       | 0       | 150.8   | 73.03   |
| 11      | Al-Okhaider      | PQ       | 1.0   | 0   | 0       | 0       | 16.3    | 7.89    |

Table (A.2). Karbala 132KV line data

| Line no. | From Bus | To Bus | R(pu)  | X(pu)  |
|----------|----------|--------|--------|--------|
| 1        | 1        | 9      | 0.016367 | 0.091959 |
| 2        | 1        | 10     | 0.021934 | 0.123238 |
| 3        | 2        | 7      | 0.005479 | 0.030788 |
| 4        | 3        | 4      | 0.009600 | 0.053939 |
| 5        | 3        | 6      | 0.012024 | 0.067561 |
| 6        | 3        | 10     | 0.015810 | 0.088831 |
| 7        | 4        | 6      | 0.020985 | 0.117908 |
| 8        | 5        | 9      | 0.007126 | 0.040038 |
| 9        | 7        | 8      | 0.007744 | 0.043514 |
| 10       | 8        | 6      | 0.005941 | 0.033380 |
| 11       | 9        | 10     | 0.005567 | 0.031278 |
| 12       | 10       | 11     | 0.039592 | 0.222454 |