



The Study of Hadramout Coast Zone Network in Circuit for Terms of Load Flow and Short Overcurrent Relay Coordination Analysis

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3

Abstract:

This research investigates the electrical network of the Hadramout Coast Zone with focus on load flow and short-circuit analysis to support optimal overcurrent relay coordination. Using simulation tools (ETAP), the load distribution, voltage profiles, fault currents, and relay settings were evaluated. The study aims to derive relay configuration that ensures selectivity, minimizes fault propagation, and improves reliability under various load and fault conditions. Results show that proper coordination can reduce mis-operations while preserving system stability.

1. INTRODUCTION

The increasing demand for reliable electric power in the Hadramout coast region highlights the need for an efficient protection system. This paper presents a technical study of load flow, short circuit analysis, and overcurrent relay coordination to enhance the protection scheme of the Hadramout Coast zone electrical network. The main goal is to ensure selectivity and speed in isolating faults while minimizing the impact on the power system.

Many studies emphasize the importance of protective device coordination to prevent cascading failures. IEC standards and IEEE guidelines have established clear methods for determining protection

settings. Previous work in Yemeni networks shows a lack of updated relay settings and poor selectivity, which can lead to system instability.

2. BACKGROUND:

Currently most power generation in Hadhramaut is based on diesel generators either from PEC owned generators or from rental power plants operated under PPA contracts. Within Sahel Hadhramout the predominant resource used for power generation is diesel. There are four power plants operated by PEC with total available capacity of 64MW. For Rayan P.S. six units are in operation. Four units are installed in 1998 and 1999. Consider an expected lifetime of twenty years decommissioning or major overhaul are required in 2018 and 2019. Generator 5 was installed in 2004 and generator 6 and 7 in 2007. Within Sheher P.S. only two out of the five generators are in operation with reduced capacity. The generators are outdated and must be replaced. Significant generation in Sheher comes from the generators under PPA contract. Within Munawarah P.S. three out of the nine generators are in operation. Date of commissioning of the generators are between 1987 and 1997. These generators are also over their lifetime and must be replaced or substantially repaired. At Khalf P.S. two generators are in operation even as the expected date for decommissioning is given with 2015. Generator in Khalf P.S. needs to be replaced in case the Power Plant will continue in producing electrical power.

In addition, there are several independent power producers feeding to the 33 kV and 11 kV Sahel power system under PPA contracts with together 98 MW capacity.

The generators in Harshyat P.S. are installed in 2010 and the expected date of decommissioning or major overhaul will be in 2030. However, the contracts for the rental power plants shall be terminated as soon as alternative generation capacity is available. This applies for rental power plants operated with HFO as well. For the small rental units feeding to the

11-kV system in Sahel area expected date of decommissioning is 2020 although these provide a significant contribution to the power supply.

Within the isolated areas small diesel generators are installed in some of the villages serving 11 kV networks for some areas or directly 0.4 kV systems. Total available generation capacity is about 11 MW, for most of the areas the generators are operated only during evening from 6 pm to midnight.

3. PROBLEM STATEMENT

When discussing the problem of overcurrent protection coordination in the coastal Hadramaut electricity network, the following points can be highlighted:

TECHNICAL CHALLENGES:

- Network Complexity: The coastal Hadramaut network is branched and complex, making coordination more difficult.
- Load Diversity: The presence of various loads (residential, commercial, industrial) affects fault current characteristics, requiring precise protection device settings.
- Equipment Age: Some equipment in the network may be aging, affecting performance and increasing the likelihood of faults.
- Environmental Impact: Harsh climatic conditions (heat, humidity) can impact the performance of protection devices.

OPERATIONAL CHALLENGES:

- Shortage of Skilled Personnel: The sector may lack qualified personnel for maintenance and coordination tasks.
- Insufficient Data: Network-related data may be inaccurate or incomplete, hindering analysis and coordination.

- Lack of a Comprehensive Maintenance System: There may be no regular maintenance system for protection devices, leading to performance degradation.

ECONOMIC CHALLENGES:

- High Maintenance and Upgrade Costs: The costs of upgrading and modernizing the protection system can be high, posing a financial challenge.
- Difficulty in Obtaining Original Spare Parts: Obtaining original spare parts for protection devices may be difficult, affecting repair and replacement.

3.1 OBJECTIVES OF SOLVING THE PROBLEM:

- Improving Network Reliability: By effectively coordinating protection devices, the number of faults can be reduced and network reliability improved.
- Develop a comprehensive coordination study to identify and address coordination issues within the network.
- Update the protection system to incorporate modern relay technologies and communication protocols.
- Improve the accuracy of fault current calculations and protection device settings.
- Establish a robust maintenance program for protection devices.
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- Develop a training program for network operators to improve their understanding of protection coordination principles.
- Implement a real-time monitoring system to detect and respond to faults more quickly.

- Minimize the economic impact of faults by reducing repair costs and outage durations.
- Optimize the use of existing network resources.

3.2 SCOPE:

This research aims to analyze short circuit and load flow in order to study the coordination of overcurrent protection devices in the coastal area network of Hadhramaut Governorate, with a particular focus on the cities of Mukalla and Ghayel Bawazir. Electrical network data up to the end of 2023 will be utilized to assess the performance of the current protection system. The analysis will be limited to the medium voltage network, with a focus on electronic and digital protection devices. The ETAP software will be used to simulate the system's performance and analyze transient conditions resulting from various fault types. The analysis will rely on the application of electrical protection theory principles, focusing on the principles of time and directional coordination.

3.3 METHODOLOGY:

The methodology involved the following steps:

Data Collection: Primary data was collected from various sources including:

Electrical network diagrams of the Hadramout coastal zone.

Existing protective relay settings.

Historical fault records.

Data Analysis: Data was analyzed using E-TAP software. This analysis determined the characteristics of the network and protective devices. Network Modeling: An electrical network model was developed using ETAP software. This model was used to analyze the network behavior under various conditions, including fault conditions.

Protective Relay Coordination: The simulation software will be used to determine the appropriate operating times for overcurrent relays to ensure that the faulty section of the network is isolated without affecting the healthy sections.

LOAD FLOW STUDY

4.1 INTRODUCTION

Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. The increasing presence of distributed alternative energy sources, often in geographically remote locations, complicates load flow studies and has triggered a resurgence of interest in the topic. In a three-phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow

3.2 OBJECTIVE OF LOAD FLOW STUDY

- Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.
- The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.
- It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- System transmission loss minimizes.

- The line flows can be known. The line should not be overloaded, it means, we should not operate the close to thermal limits.

4.3 REQUIREMENTS OF A DISTRIBUTION SYSTEM

It is mandatory to maintain the supply of electrical power within the requirements of many types of consumers. Following are the necessary requirements of a good distribution system:

(a) Availability of power demand: Power should be made available to the consumers in large amount as per their requirement. This is very important requirement of a distribution system.

(b) Reliability: As we can see that present-day industry is now totally dependent on electrical power for its operation. So, there is an urgent need of a reliable service. If by chance, there is a power failure, it should be for the minimum possible time at every cost. Improvement in reliability can be made up to a considerable extent by a) Reliable automatic control system.

b) Providing additional reserve facilities.

(c) Proper voltage: Furthermost requirement of a distribution system is that the voltage variations at the consumer terminals should be as low as possible. The main cause of changes in voltage variation is variation of load on distribution side which has to be reduced. Thus, a distribution system is said to be only good, if it ensures that the voltage variations are within permissible limits at consumer terminals. (d) Loading: The transmission line should never be over loaded and under loaded. (e) Efficiency: The efficiency of transmission lines should be maximum say about 90%.

4.4 LOAD FLOW REPORT

By using E tap software, we get the following results:

Bus				Generation		Load		Load Flow					XFMR
IID	kV	% Mag.	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	%Tap
B	6.600	103.745	-40.1	0.000	0.000	0.000	0.000	FU-BB2 & Bm15	0.000	0.000	0.0	0.0	-
B-AH 6MW 1	0.400	97.000	22.0	1.800	1.116	0.000	0.000	B-AH 6MW 11KV	1.800	1.116	3151.1	85.0	-
*B-AH 6MW 1-1	0.400	100.000	21.8	1.800	3.037	0.000	0.000	B-AH 6MW 11KV-1	1.800	3.037	5095.0	51.0	-
B-AH 6MW 1-1-1	0.400	97.278	22.1	1.800	1.116	0.000	0.000	B-AH 6MW 11KV-1-1	1.800	1.116	3142.1	85.0	-
B-AH 6MW 1-1-2	0.400	96.893	51.9	1.800	1.116	0.000	0.000	B-AH BS2 10MW 11KV	1.800	1.116	3154.6	85.0	-
B-AH 6MW 1-1-2-1	0.400	96.893	51.9	1.800	1.116	0.000	0.000	B-AH BS1 10MW 11KV	1.800	1.116	3154.6	85.0	-
B-AH 6MW 1-3	0.400	99.956	51.1	2.700	1.673	0.000	0.000	B-AH 6MW 11KV-2	2.700	1.673	4586.9	85.0	2.500
B-AH 6MW 2	0.400	97.000	22.0	1.800	1.116	0.000	0.000	B-AH 6MW 11KV	1.800	1.116	3151.1	85.0	-
B-AH 6MW 2-1	0.400	98.219	22.7	2.700	1.673	0.000	0.000	B-AH 6MW 11KV-1	2.700	1.673	4668.0	85.0	-
B-AH 6MW 2-1-1	0.400	97.278	22.1	1.800	1.116	0.000	0.000	B-AH 6MW 11KV-1-1	1.800	1.116	3142.1	85.0	-
B-AH 6MW 2-1-2	0.400	97.801	52.6	2.700	1.673	0.000	0.000	B-AH BS2 10MW 11KV	2.700	1.673	4687.9	85.0	-

1ID	Bus			Generation		Load		Load Flow				XFMR	
	kV	% Mag.	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
B-AH 6MW 2-1-2-1	0.400	97.801	52.6	2.700	1.673	0.000	0.000	B-AH BS1 10MW 11KV	2.700	1.673	4687.9	85.0	-
B-AH 6MW 2-2	0.400	98.384	22.7	2.700	1.791	0.000	0.000	B-AH 6MW 11KV-1	2.700	1.791	4753.0	83.3	-
B-AH 6MW 2-2-1	0.400	98.384	22.8	2.700	1.791	0.000	0.000	B-AH 6MW 11KV-1-1	2.700	1.791	4754.7	83.3	-
B-AH 6MW 2-2-2	0.400	98.806	52.5	2.700	2.389	0.000	0.000	B-AH BS2 10MW 11KV	2.700	2.389	5266.8	74.9	-
B-AH 6MW 2-2-1	0.400	97.967	52.6	2.700	1.791	0.000	0.000	B-AH BS1 10MW 11KV	2.700	1.791	4773.2	83.3	-
B-AH 6MW 2-3	0.400	98.219	22.7	2.700	1.673	0.000	0.000	B-AH 6MW 11KV-1	2.700	1.673	4668.0	85.0	-
*B-AH 6MW 2-5	0.400	100.000	50.3	1.800	1.781	0.000	0.000	B-AH 6MW 11KV-2	1.800	1.781	3655.0	71.1	2.500
B-HIPC1-1 11KV	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC1 33KV	6.000	2.906	343.9	90.0	-
B-HIPC1-2 11KV	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC1 33KV	6.000	2.906	343.9	90.0	-
B-HIPC1-3 11KV	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC1 33KV	6.000	2.906	343.9	90.0	-
B-HIPC1 33KV	33.000	99.736	-5.3	0.000	0.000	0.000	0.000	HR-BB1	17.957	7.860	343.9	91.6	-

Bus				Generation		Load		Load Flow					XFMR	
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	% Tap	
								B-HIPC1-1 11KV	-5.986	-2.620	114.6	91.6	-	
								B-HIPC1-2 11KV	-5.986	-2.620	114.6	91.6	-	
								B-HIPC1-3 11KV	-5.986	-2.620	114.6	91.6	-	
B-HIPC2-1 11KV	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC2 33KV	6.000	2.906	343.9	90.0	-	
B-HIPC2-1 11KV1	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC2 33KV	6.000	2.906	343.9	90.0	-	
B-HIPC2-1 11KV2	11.000	101.760	26.9	6.000	2.906	0.000	0.000	B-HIPC2 33KV	6.000	2.906	343.9	90.0	-	
B-HIPC2 33KV	33.000	99.736	-5.3	0.000	0.000	0.000	0.000	HR-BB3	17.957	7.860	343.9	91.6	-	
								B-HIPC2-1 11KV	-5.986	-2.620	114.6	91.6	-	

Table 1: Load flow report

This table presents the results of a load flow analysis, including bus voltages, power generation, load demand, and power flows across the network.

Voltage levels are maintained within operational limits, with minor deviations observed at some buses.

Power generation is balanced against total load, ensuring system stability.

The load flow section details MW and MVar values for each line, helping identify heavily loaded or lightly utilized feeders.

Overall, the system operates efficiently, with stable voltage profiles and no critical overloads detected.

The system is generally stable but exhibits signs of high transformer loading and localized power flows. Strategic upgrades and load management are recommended to ensure long-term reliability.

- The system operates within safe and efficient parameters.
- No major mismatch was observed (system mismatch = 0).
- Voltage control and load balancing appear stable across critical buses.
- Recommendations:
- Perform routine load flow analysis after major expansions.
- Improve PF where values drop below 85% to reduce system losses.
- Monitor motor loads to avoid excessive reactive power draw.

▪Bus Voltage and Load Summary:

- The network consists of several buses operating at different voltage levels. Below is a summary of 0.433 kV, 11 kV, and 33 kV.
- The voltage levels at various buses range from 94.1% to 102.4% of nominal values. Notably:
- Bus B.GHA.33 has the lowest voltage magnitude (94.1%).
- Buses B.ESS1 and B.ESS2 have the highest voltage magnitudes (102.4%).

This indicates acceptable voltage variation within $\pm 10\%$, though B.GHA.33 is close to the lower limit.

- Major generation was recorded at bus HR-BB4 (23.9 MW) and HR-HY-BB (4.1 MW).
- Maximum load observed:
- FU-BB5: 4.344 MW,
- HR-BB4: 6.426 MW, - HY-BB2: 9.416 MW.

▪Load Flow Analysis:

- Power transfer between buses shows both positive and negative flow directions depending on the load distribution.
- Highest power transfer recorded:
- MN-BB1 → MN-BB2: 13.715 MW,
- HR-BB1 → B-HHTC 33kV: -17.957 MW,
- HR-HY-BB → HY-BB1: 19.046 MW.
- Voltage drops and current flow indicate system stress mainly at some 33kV interconnections.
- Voltage Deviation: Most buses maintain voltages close to nominal values. Any deviation should be within $\pm 5\%$ tolerance.
- Line Losses: Power losses across branches have been recorded and are considered acceptable for the current design.
- Generator Bus Performance: Generators are supplying the required power with stable voltage levels.

▪Significant real power flows (MW) include:

- From B.GHNG to B.GHNG33: -5.487 MW, indicating power export.
- From B.SS 15 HAR SS 2 132KV to BRAYAN SS 2 132KV: 18.539 MW
- Reactive power (Mvar) flow also observed, e.g.:
- 3.404 Mvar from B.GHNG to B.GHNG33.

- Indicates inductive nature and lagging power factor.
- Observations and Recommendations:
 - Voltage profile is mostly stable; however, HY-BB2 and HR-BB1 show noticeable voltage drops.
 - Transformer tap settings should be reviewed to maintain better voltage regulation.
 - Recommend checking loading on HY-BB2 as it appears heavily loaded (9.4 MW).
 - Consider reactive power compensation to improve power factor and reduce losses.
 - Voltage deviations are within tolerable limits but should be monitored.
 - Transformer loading at BRY substations suggests high stress; consider load balancing or capacity increase.
 - Generation is limited to specific nodes; consider distribution for system reliability.
 - Reactive power flow shows system operating with lagging PF, requiring capacitor banks evaluation.

The system shows good overall performance, but with areas requiring further optimization, particularly in voltage regulation and reactive power management.

4. SHORT-CIRCUIT CALCULATIONS

5.1 INTRODUCTION

Short-circuit currents can create massive destruction to the power system. Short circuits typically have magnitudes many times greater than load currents. The consequences of these high-magnitude currents can be catastrophic to normal operation of the power system.

First, the presence of short-circuit currents in system conductors results in additional heating, which the system is usually not designed to sustain continuously. These currents also introduce severe mechanical forces on conductors, which can break insulators, distort transformer windings, or cause other physical damage.

The flow of high-magnitude short-circuit currents through system impedances may also result in abnormally low voltages, which in turn lead to otherwise healthy equipment being forced to shut down. Finally, at the point of the short circuit itself, generally the release of energy in the form of an arc, if left uncorrected, can start a fire, which may spread well beyond the point of initiation.

5.2 SHORT CIRCUIT ANALYSES

Short Circuit analysis is required to ensure the existing and new equipment ratings are sufficient at each point in the electrical system. A Short Circuit Analysis will help to ensure that equipment is protected by establishing proper interrupting ratings of protective devices. If an electrical fault exceeds the interrupting rating of the protective device, the consequences can be devastating. It can be a serious threat to human life and is capable of causing injury, extensive equipment damage, and costly. On large systems, short circuit analysis is required to determine both the switchgear ratings and the relay settings. No substation equipment can be installed without knowledge of the complete short circuit values for the entire power distribution system. The short circuit calculations must be maintained and periodically updated to protect the equipment and the lives.

5.3 BENEFITS OF A SHORT CIRCUIT ANALYSIS:

performing a short circuit Study provides the following benefits:

- 1.Reduces the risk a facility could face and help avoid catastrophic losses.
2. Increases the safety and reliability of the power system and related equipment.
- 3.Identifies problem areas in the system.
- 4.Identifies recommended solutions to existing problems.

5.4 SHORT-CIRCUIT REPORT

The purpose of this study is to analyze the 3-phase short-circuit current at the 132 kV bus B.S 15 HAR SS 1 using IEC 60909 standards. This helps determine the electrical stress on equipment and supports protective device coordination.

This report evaluates the short-circuit duty for various devices in the system and compares it with their rated short-time withstand current capacities. It helps ensure all equipment operates safely under fault conditions.

Table 2: Short circuit report

Bus ID	Device ID	Device Capacity			3-Phase Short-Circuit Duty Results		
		I _{thr} (kA)	T _{kr} (sec.)	Rated Thermal Energy (MJ)	I _{th} (kA)	T _{kr} (sec.)	Thermal Energy (MJ)
HR-BB1	HR-CB6	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB1	HR-CB4	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB1	HR-CB9	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB1	HR-CB7	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB4	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB2	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB3	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB13	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB14	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	HR-CB1	25.000	3.00	1875.00	12.008	3.00	432.59
HR-BB3	CB52	40.000	3.00	4800.00	12.008	3.00	432.59
RY-BB1	RY-CB1	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB1	RY-CB2	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB1	RY-CB4	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB1	RY-CB5	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB1	RY-CB7	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB1	RY-CB17	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB1	RY-CB3	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB2	RY-CB7	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB2	RY-CB11	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB2	RY-CB12	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB2	RY-CB14	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB2	RY-CB16	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB3	RY-CB16	40.000	3.00	4800.00	36.699	3.00	4040.50
RY-BB3	RY-CB19	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB3	RY-CB18	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB3	RY-CB24	25.000	3.00	1875.00	36.699	3.00	4040.50 *
RY-BB3	RY-CB25	25.000	3.00	1875.00	36.699	3.00	4040.50 *

* Note: Values with (*) indicate that the Short-Circuit Thermal Energy exceeds the Device Rated Thermal Energy.

• Fault Parameters:

- Nominal Voltage: 132.000 kV
- Voltage Correction Factor (c): 1.10 (for maximum fault current)
- Peak Fault Current (Method C): 5.224 kA
- Steady-State Fault Current (rms): 1.956 kA

• **Observations:**

- The highest individual contribution to the fault came from B-HIFC buses, showing significant strength (high X/R ratio: 47.4).
- The fault current contributions have realistic X/R ratios, confirming proper system impedance modeling.
- Many buses show zero contribution, indicating they are electrically distant or isolated from the faulted bus under the analyzed condition.

• **Conclusion:**

The total 3-phase fault current at B.S 15 HAR SS 1 is 1.956 kA (rms), with a peak of 5.224 kA, indicating a moderately strong fault. Protection equipment at this location should be rated accordingly. The fault current contributions are dominated by a few key buses, which are critical for protection coordination.

The system is generally within safe operating limits. However, certain circuit breakers (especially in the RY bus section) are overloaded or close to limits and need urgent review or upgrading.

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