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Engineering

RELAY CO-ORDINATION AND ARC FLASH ANALYSIS USING ETAP

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ABSTRACT Relays and circuit breakers are heart of the modern large interconnected power system. Proper co-ordination of relays is essential to minimize unnecessary outages. The arc flash hazard is related to electrical safety in work place. The calculations required for determining arc-flash incident energy exposure for electrical workers are involved. The authors have completed arc-flash energy studies for many industrial sites, from small facilities to large chemical plants. This paper provides a summary of the results of these studies, with an emphasis on the wide range of results that were found. Learning's about electrical equipment design, installation and operation are discussed that were found to be associated with high arc-flash energy values. In addition, some methods are described to evaluate the arc-flash energy values for a facility that can help the owner determine the most effective arc flash hazard management policy.

KEYWORDS : Relay co-ordination,arc flash analysis ,ETAP software,arc flash boundary,PPE(personal protective equipments)

1. INTRODUCTION

This approach will need the computer simulation work using two power system studies, namely, an over current protective device(OCPD) coordination study and an arc flash hazard analysis. A few iterations might be needed between the two studies in order to obtain optimal results. Techniques have been presented that enhance protection reliability and preserve selective coordination throughout the system.

In most cases, the selection of a primary OCPD will have significant impact on the AF energy and the viability of efficiently reducing this energy to acceptable levels. Worst level incident energy of various voltage level switchgear are presented .An approach to reducing the arc flash hazard for existing industrial and commercial facilities is proposed. Although every facility has its own issues or concerns, this practical approach shall be able to significantly improve the arc flash safety in existing facilities. The incident energy analysis method for arc flash PPE selection recommended by NFPA.Quantified results on the arc flash hazard reductions, computer simulation using ETAP is conducted for a large oil field facility and a manufacturing facility in industrial building as case studies, and the simulation results for the case studies are presented.

2. SYSTEM MODEL

The GDC Putrajaya Plant 1 has a maximum connected demand of 22.60 MW. GDC draws power from two TNB PMU's namely PMU Abu Bakar Baginda and PMU NUNI through underground cables of 4kM and 9kM length respectively, which are terminated to the 33kV bus bar 1L and 33kV Bus bar 1R capacity for relay coordination, which is as shown in fig1.

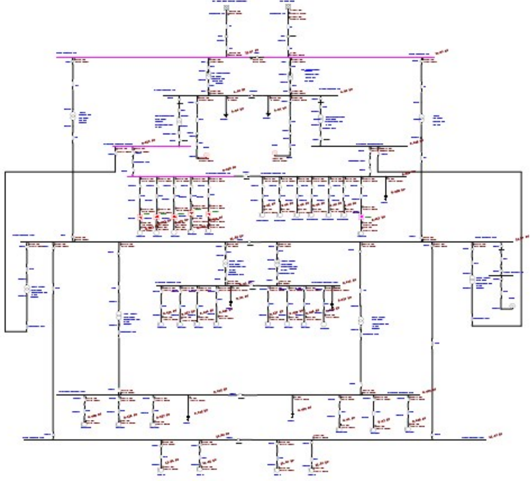


Fig 1 single line diagram of GDC Putrajaya Plant 1

3. RELAY COORDINATION

Relay coordination is essential to obtain continuous operation of system, to provide best service to the consumer and earn the most revenue.

- Quickly isolated the faulty area
- To minimize the magnitude of fault current
- To minimize the operation fault

3.1 primary and back up protection

- Primary protection :Device closest to the fault
- Back up protection :Device next in the line
- Security: if the primary protection fails to maintain the integrity of the system, back up protection should operate.
- Reason for providing back up protection: Failure of primary protection.

3.2 Stage 51(Phase and Neutral)

- 51 is the overcurrent Relay. This relay has a phase and neutral protection they are 51p&50n.

$$pickup(51p) = \frac{1.1*FLA}{CTratio}$$

FLA= Full load current
Curve type: IEC Extremely inverse.

$$pickup(51n) = \frac{0.2*FLA}{CTratio}$$

Curve type: IEC standard inverse.

3.3 stage 50(phase and Neutral)

- 50 is the instantaneous overcurrent protection relay this relay have a phase and neutral protection 50p & 50n.

$$pickup(50p) = \frac{1.3*LRA}{CTratio}$$

LRA =locked rotor current
Curve type: DMT (instantaneous)

$$pickup(50n) = \frac{FLA}{CTratio}$$

FLA= full load amps
Curve type: DMT (instantaneous)

3.4 Relay coordination for two bus system

Study is repeated with the change in various relay characteristic curves like definite time, normal inverse, Very inverse and extreme inverse characteristics. Settings with minimum arc Flash level are selected as optimal fit for the system. Following studies are carried out,

- Load Flow Analysis

- Short Circuit Studies
- Relay coordination
- Arc Flash studies

3.5 Stage 51 setting

Table 1 shown in stage 51 setting for relay. These settings are calculated by Etap software.

Table 1 stage 51 setting for relay

Relay id	CT ratio	Pickup value	Curve type	Time dial
Relay 3	150:1	0.615	IEC-EXTREMELY INVERSE	1.1
Relay 4	200:1	0.759	IEC-EXTREMELY INVERSE	1.5
Relay 2	2500:1	0.501	IEC-STANDARD INVERSE	0.125
Relay 1	400:1	1	IEC-EXTREMELY INVERSE	0.3

3.6 stage 50 setting

Table 2 stage 50 setting

Relay id	CT ratio	Pickup value	Curve type	Time dial
Relay 3	150:1	11.25	INSTANTANEOUS	0.01
Relay 4	200:1	10.16	INSTANTANEOUS	0.01
Relay 2	2500:1	3	INSTANTANEOUS	0.21
Relay 1	400:1	9.7	INSTANTANEOUS	0.3

3.6 Relay coordination output for two bus system

If proper co-ordination is not done, then CB incomer trips for any fault on the outgoing feeder. Instead of tripping one load, an entire bus is lost .Fig 2 shown in proper co-ordination only relevant CB trips isolating the faulty equipment at the earliest. This minimizes the damage.

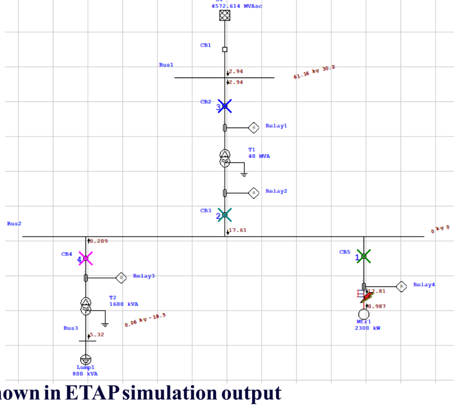


Fig 2 shown in ETAP simulation output

3.6 curves representing arcing currents

A time-over current relay characteristics generally plotted as a single line curve shown in fig2.Curves for specific relays are provided by the manufacturer on log paper and include the available range of time delay settings. Electromechanical time overcurrent relays that have a dial with continuous adjustment from typically 0.5 to 10 mill sec.

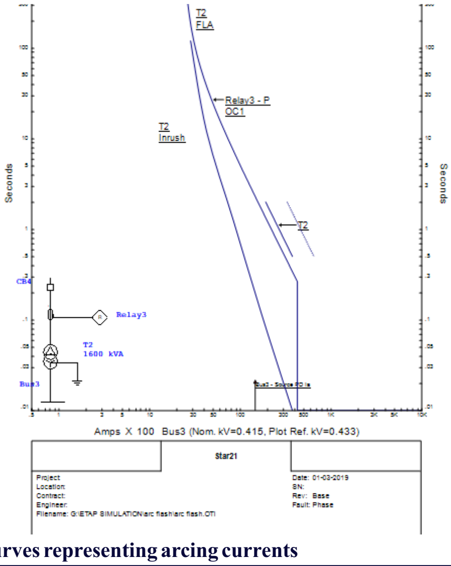


Fig 3 curves representing arcing currents

3.7 Time taken for relay operation

The pickup current selection provides the flexibility to move the characteristic left and right on the coordination plot, and the time dial provides adjustment up and down. Time taken for relay operation shown in fig 4

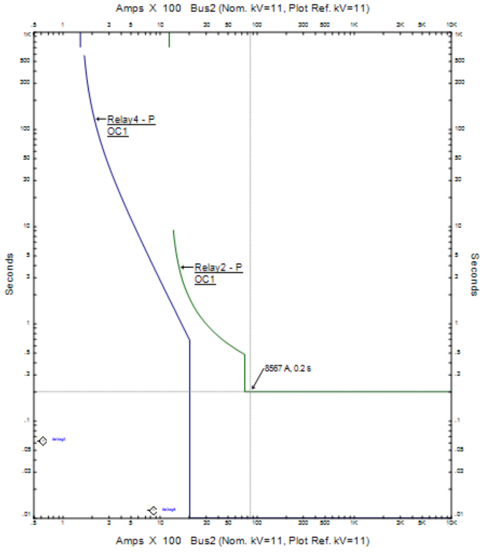
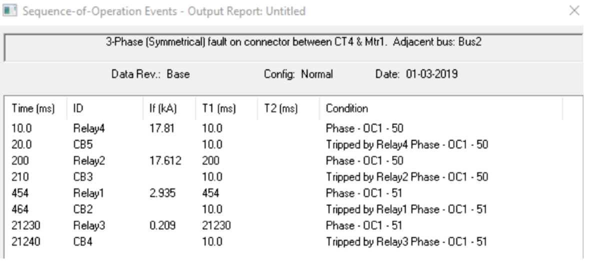


Fig 4 time taken for relay operation

3.8 Simulation output


Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between CT4 & Mtr1. Adjacent bus: Bus2

Data Rev.: Base Config: Normal Date: 01-03-2019

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay4	17.81	10.0		Phase - OC1 - 50
20.0	CB5		10.0		Tripped by Relay4 Phase - OC1 - 50
200	Relay2	17.612	200		Phase - OC1 - 50
210	CB3		10.0		Tripped by Relay2 Phase - OC1 - 50
454	Relay1	2.935	454		Phase - OC1 - 51
464	CB2		10.0		Tripped by Relay1 Phase - OC1 - 51
21230	Relay3	0.209	21230		Phase - OC1 - 51
21240	CB4		10.0		Tripped by Relay3 Phase - OC1 - 51

Fig 5 Etap simulation output

4. ARCFLASH ANALYSIS

An arc flash begins when the electricity exits its intended path and begins traveling through the air toward a grounded area. Once this happens, it ionizes the air, which further reduces the overall resistance along the path that the arc is taking. This helps draw in additional electrical energy. The arc will travel toward a ground of some type, which will typically be whatever objects are closest to its source. The exact distance that an arc flash can travel is known as the arc flash boundary. This is determined by the potential energy present and a variety of other factors such as air temperature and humidity.

4.1 NFPA 70e and arc flash hazard

NFPA 70E defines a series of boundaries relating to electrical safety when working on energized equipment. Only "qualified" people can enter these boundaries and they are required to wear appropriate PPE within these boundaries. The four protection boundaries are shown in fig 6

- Flash Protection Boundary
- Limited Approach Boundary
- Restricted Approach Boundary
- Prohibited Approach Boundary

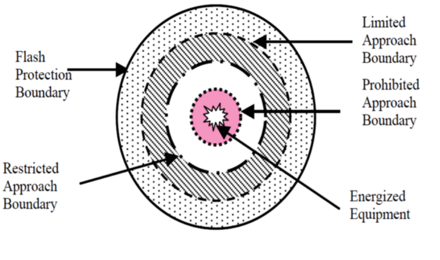


Fig 6 Arc flash boundary

4.2 Personal Protective Equipment

NFPA specifies the requirement of personal protective equipment (PPE) for workers within the flash protection boundary. All parts of the body which may be exposed to the arc flash need to be covered by the appropriate type and quality of PPE. The entire PPE set may be comprised of FR clothing, helmet or head gear, face shield, safety glasses, gloves, shoes, etc. depending upon the magnitude of the arc energy. The amount of PPE required and its quality needs to be determined on the basis of the calculated incident energy on the worker's body. fig 7 shown in PPE category level chart NFPA 2009

Fig 7 PPE category level chart NFPA 2009

4.3 Determine the arc fault currents

The arc fault current depends primarily on the bolted fault current. The bolted fault current in the protective device can be found from the short-circuit study by looking at a one-bus-away run. This will separate fault contributions from normal feeder, alternate feeder, and downstream motors.

The arc fault currents can then be calculated. The calculated arc fault current will be lower than the bolted fault current due to arc impedance, especially for applications under 1000V. For medium voltage applications the arc current is still lower than the bolted fault current, and it must be calculated.

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526\,G + 0.5588V(\lg I_{bf}) - 0.00304\,G(\lg I_{bf})$$

Where:

$\lg I_a$ is log10 of arc current (kA)

K is – 0.153 for open configurations

k is – 0.097 for box configurations.

$\lg I_{bf}$ is log 10 of bolted fault current (symmetrical RMS) (kA)

V is system voltage (kV)

G is distance between buses (mm)

Table 3 Arc flash outputs

Bus id	Bolted current (ka)	Arching current (ka)	Incident energy (cal/cm^2)	Arcflash boundary (m)	Energy level PPE (NFPA 70E)
Bus 1	40.19	40.19	649.23	10.66	Exceed maximum level
Bus 1	40.19	40.19	649.23	10.66	Exceed maximum level
Bus 3	38.47	17.13	147.464	5.067	>4

4.4 Arc flash output for two bus system

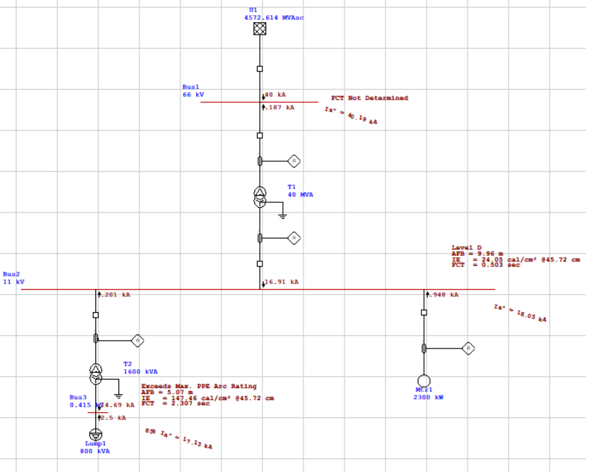


Fig 8 Etap simulation output for arc flash analysis

4.5 simulation output

Arc-Flash Look-Up Table IEEE 1584 Standard

Incident Energy Exposure (calorie/cm²)

Bus				Arc Duration		Arc in Open Air						Arc in Cubic Box					
						Arc Flash Boundary (ft)	Distance from Arc Electrodes (inches)					Arc Flash Boundary (ft)	Distance from Arc Electrodes (inches)				
ID	kV	Isc (kA)	Grounding	Seconds	cycles		18	24	30	36	48		18	24	30	36	48
Bus1	66.000	40.186	Grounded	0.005	0.25	7.8	32.49	18.28	11.70	8.12	4.57						
				0.010	0.50	11.1	64.99	36.55	23.40	16.25	9.14						
				0.040	2.00	22.1	259.95	146.22	93.58	64.99	36.55						
				0.060	3.00	27.1	389.92	219.33	140.37	97.48	54.83						
				0.080	4.00	31.3	519.89	292.44	187.16	129.97	73.11						
				0.100	5.00	35.0	649.86	365.55	233.95	162.47	91.39						
				0.120	6.00	38.3	779.84	438.66	280.74	194.96	109.66						
				0.160	8.00	44.2	1039.78	584.88	374.32	259.95	146.22						
				0.200	10.00	49.5	1299.73	731.10	467.90	324.93	182.77						
				0.400	20.00	69.9	2599.46	1462.19	935.80	649.86	365.55						
				0.600	30.00	85.7	3899.19	2193.29	1403.71	974.80	548.32						
				0.800	40.00	98.9	5198.91	2924.39	1871.61	1299.73	731.10						
				1.000	50.00	110.6	6498.64	3655.49	2339.51	1624.66	913.87						
				1.200	60.00	121.1	7798.37	4386.58	2807.41	1949.59	1096.65						
				1.400	70.00	130.9	9098.10	5117.68	3275.32	2274.52	1279.42						
				1.600	80.00	139.9	10397.83	5848.78	3743.22	2599.46	1462.19						
				1.800	90.00	148.4	11697.55	6579.87	4211.12	2924.39	1644.97						
				2.000	100.00	156.4	12997.28	7310.97	4679.02	3249.32	1827.74						
				2.200	110.00	164.0	14297.01	8042.07	5146.92	3574.25	2010.52						
				2.400	120.00	171.3	15596.74	8773.17	5614.83	3899.19	2193.29						
Bus2	11.000	18.794	Grounded	0.005	0.25	0.6	0.19	0.10	0.07	0.05	0.03	0.3	0.24	0.18	0.15	0.12	0.09
				0.010	0.50	0.8	0.37	0.21	0.13	0.09	0.05	0.6	0.48	0.36	0.29	0.24	0.18
				0.040	2.00	1.7	1.49	0.84	0.54	0.37	0.21	2.4	1.91	1.44	1.16	0.97	0.74

Fig 9 arc flash simulation output

5. CONCLUSION AND RECOMMENDATIONS

- Characteristics curves which are inherent properties of the protection relays are playing important role in clearing the fault.
- Multi stage protection available in numerical relays are utilized to minimize the Arc Energy (I2t)
- Based on how quick the relays are acting to the fault is determining the fault clearing time and the incident energy level and arc flash boundary level.
- Various characteristic curves are used to find best possible settings.
- System grounding which is foremost important to identify the fault happening in the system is also playing major role in reducing the fault level, so that the incident energy level is getting reduced.

5.1 SCOPE OF FUTURE WORK

- Possibilities to reduce the Arc flash levels and its mitigation in the ungrounded system.
- Possibilities of reducing the arc flash level with help of other protection devices viz., fuse, MCB, Contactors, etc.,
- Ensuring the arc flash level to bare minimum based on the other system design considerations.

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