ECE385

HW7

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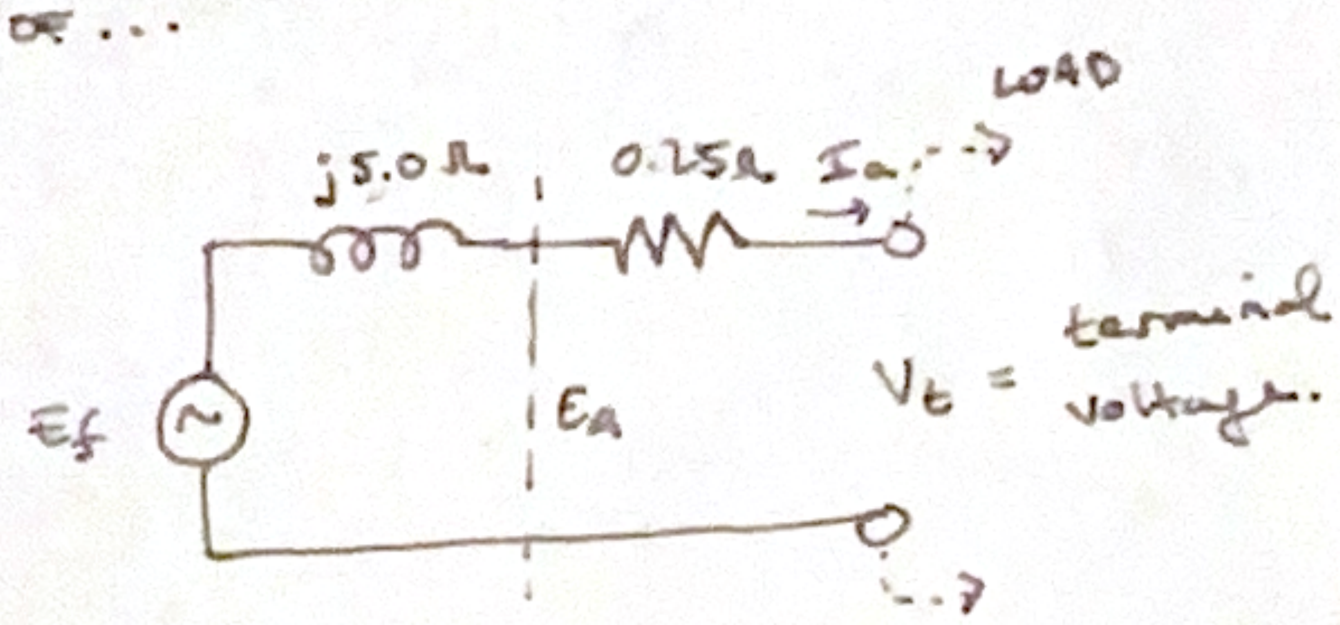
11/22/2024

(1) A 3ϕ, 10kVA, 220V, Y-connected synchronous generator has $R_a = 0.25\Omega$ per phase and $X_s = 5.0\Omega$ per phase. Determine the excitation voltage, E_f, when the generator is delivering full load @ pf of...



(A) pf = 0.85 lagging.

$S_{rated} = 10kVA$
$pf = 0.85$ lag.
$V_L = 220V$

First, we need the phase voltage at the terminals, V_t.

$$V_t = \frac{1}{\sqrt{3}}(220V) = 127V.$$

From this we can find the current in one phase, I_a, knowing the rated power 10kVA, and voltage $V_t = 127V$.

$$\Rightarrow \quad |S_{rated}| = 3|V_t||I_a| \rightsquigarrow |I_a| = \frac{|S_{rated}|}{3|V_t|} = \frac{10kVA}{3(127V)} = 26.2A$$

The phase angle $\to$ $\theta = \cos^{-1}(0.85) = 31.8°$ $\to$ $I_a = 26.2\angle -31.8° A$

↑ negative since current lags in lagging load.

KVL

$$-E_f + I_a(0.25 + j5.0) + V_t = 0$$

$$\Rightarrow E_f = (26.2\angle -31.8°)(0.25 + j5.0) + 127$$

$$= \boxed{228.65\angle 28.2° V}$$

(B) pf = 1.0

$\theta = \cos^{-1}(1.0) = 0°$ $\therefore$ $I_a = 26.2\angle 0° A.$

$$\Rightarrow E_f = (26.2\angle 0°)(0.25 + j5.0) + 127$$

$$= \boxed{187.1\angle 44.4° V}$$

(C) pf = 0.8 leading

$\theta = \cos^{-1}(0.8) = 36.9°$, leading so current leads $\therefore$ $\theta_I = 36.9°$ as well $\therefore$ $I_a = 26.2\angle 36.9° A$

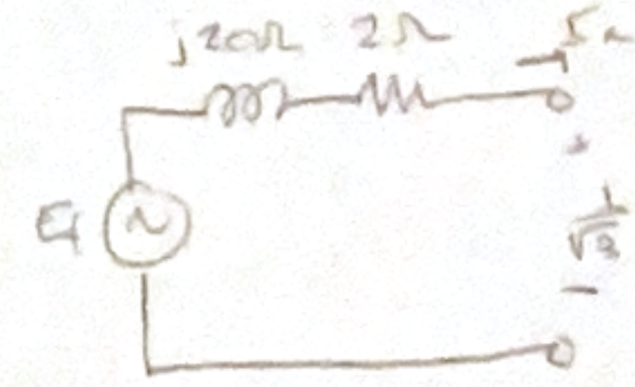
$$\Rightarrow E_f = (26.2\angle 36.9°)(0.25 + j5.0) + 127$$

$$= \boxed{121.2\angle 63.8° A}$$

② A 3ϕ, 14 kV, 10 MVA, 60 Hz, 2 pole, 0.85 pf lagging, Y-CONNECTED

SYNCHRONOUS GENERATOR HAS $X_s = 20\Omega$ PER PHASE AND $R_s = 2\Omega$ PER PHASE.

THE GENERATOR IS CONNECTED TO AN INFINITE BUS.



Ⓐ DETERMINE THE EXCITATION VOLTAGE AT THE RATED CONDITION. DRAW THE PHASOR DIAGRAM.

has no phase angle so really

$V_t = 8.083\angle 0°$ kV

P = 2

pf = 0.85 lag

S_{rated} = 10 MVA

V_L = 14 kV

$$V_t = \frac{1}{\sqrt{3}}(14\text{kV}) = 8083\text{ V}$$

$$|I_a| = \frac{|S_{rated}|}{3|V_t|} = \frac{10\text{MVA}}{3(8.083\text{kV})} = 412.4\text{ A}$$

$$\theta_I = -\theta = -\cos^{-1}(0.85) = -31.8°$$

b/c lagging

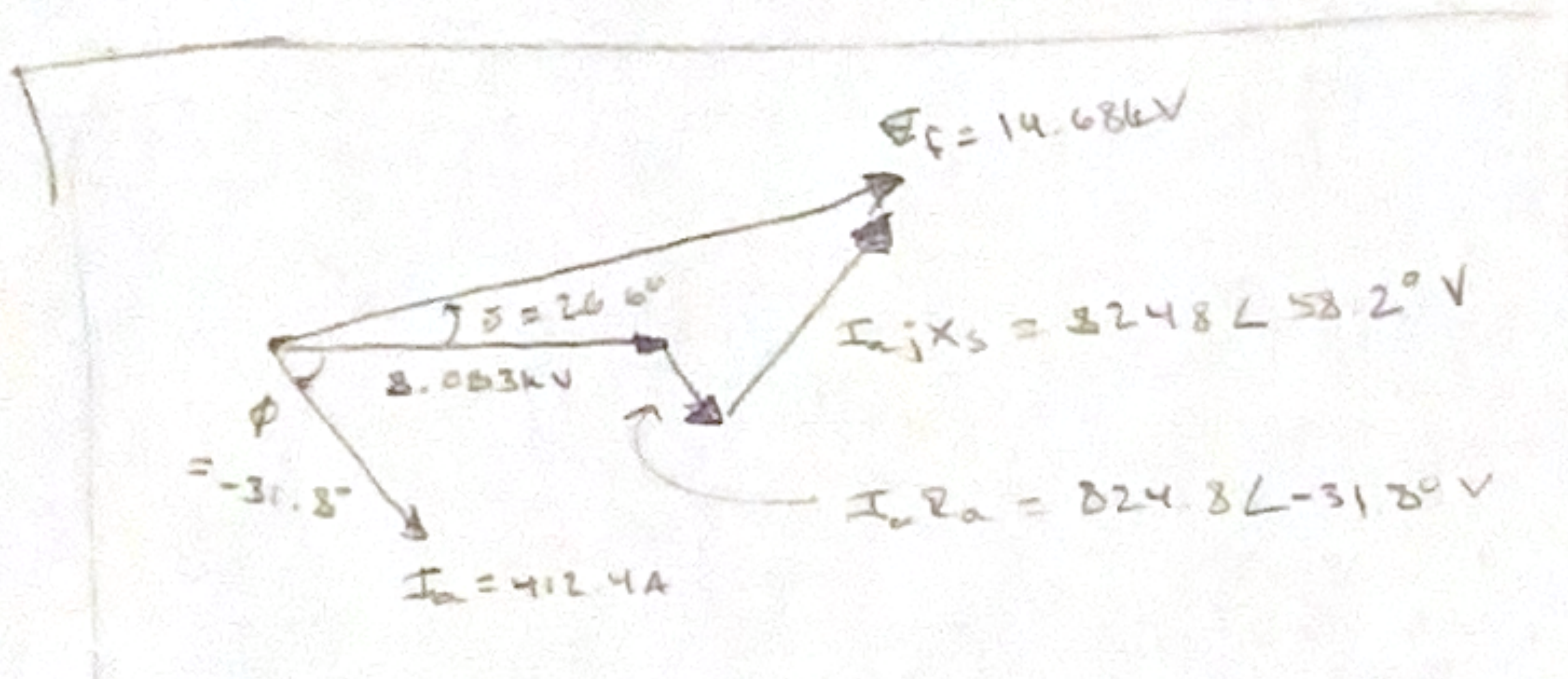
$$\underline{I_a = 412.4\angle -31.8°\text{ A}}$$

KVL

$$E_f = (412.4\angle -31.8°)(2+j20) + 8.083\text{kV}$$
$$= \boxed{14.68\angle 26.6°\text{ kV}}$$

FROM THE ABOVE $|E_f|\angle\delta° \Rightarrow |E_f| = 14.68$ kV, $\delta = 26.6°$

PHASOR DIAGRAM



Ⓑ DETERMINE POWER (TORQUE) ANGLE AT RATED CONDITION.

δ IS THE POWER TORQUE ANGLE, WHICH ABOVE $\boxed{\delta = 26.6°}$

Ⓒ IF FIELD CURRENT IS CONSTANT, DETERMINE THE MAX POWER THE GENERATOR CAN SUPPLY.

$$P_{max} = \frac{3E_f V_t}{X_s} = \frac{3(14.68\text{kV})(8.083\text{kV})}{20\Omega} = \boxed{17.8\text{ MW}}$$

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ECE385

11/29/2024

Northeast Blackout of 2003

1) What caused the outage?

The Northeast Blackout of 2003 was caused by a lack of reactive power in the Northeast region of Ohio, near Cleveland, which was demanded by the air conditioning units in the area turning on during the summer day. Capacitor banks to provide the needed reactive power were not in service, so the Eastlake 5 generation substation overexcited its generators. The generators were pushed beyond capacity, and faults dropped the generators from the grid.

However, the issue was largely exacerbated by software malfunctions at the FirstEnergy Corporation in Akron, Ohio. FirstEnergy (FE) is a Control Area under the North American Electric Reliability Corporation's East Central Area Reliability Coordination Agreement (NERC ECAR) region. A bug in the alarm system used by FE Control Room operators prevented real-time faults to be seen, and the FE IT staff failed to communicate the issue to the operators.

The Midwest Independent System Operator, which was the area's reliability coordinator, failed to receive real-time data about faults in the Dayton Power and Light Stuart Atlanta 345-kV line, which prevented their State Estimator to converge, and the proper contingency simulations MISO needed to stay ahead of issues was effectively offline.

Since MISO and FE were flying blind, and FE capacitor banks were out-of-service, transmission lines around Cleveland began to overcurrent. The Harding-Chamberlain line sagged and short-circuited on trees, and the same followed for the Hanna-Juniper and Star-Canton lines. This caused the load to move to the Sammis-Star line, now operating at 120% rated current, which caused circuit-protecting relays to trip. As power from the South of Cleveland was cutoff, overloads in lines from Michigan and Indiana caused load to surge from the East through Pennsylvania, tripping the remaining lines in the region.

2) What factors contributed to the duration and size of the outage?

The lack of proper monitoring of the transmission lines in the NERC ECAR region caused the large size of the outage. FE Control Room operators were unaware of the incoming faults as generation station engineers watched mayhem unfold.

Largely, NERC found FE violated numerous NERC standards regarding proper understanding of voltage criteria and needs, effective and routine contingency analyses, and standards for updating operators on the functionality of monitoring tools.

The FE Control Room and IT department had insufficient communication that the computer monitoring system was compromised.

Also, MISO had insufficient data on the location of transmission line breakers, which prevented from the effective dispatch of linemen to begin fixing the outages.

3) How did the use of the "Infinite Bus" contribute to or limit the outage?

The US-Canada Power System Outage Task Force's final report on the outage outlined to major causes of complexity in maintaining the infinite bus:

1. It is not economical to store electrical energy in the grid, so electricity is generated the moment it is used.
2. Electricity does not flow like water, but instead along the easiest path. To combat this, complex control devices are required.

The "Infinite Bus" contributed to the Blackout in the sense that once transmission lines in the region failed, or generation stations dropped off, the load in Northeast Ohio still needed to be fed by remaining lines. The lines that were pushed harder as a result, sagged from the heat of increasing current and shorted on nearby trees.

4) What learnings came from the outage related to technical, operational, and ethical considerations for engineers?

The main learnings from the Northeast Blackout of 2003 are increases in standards and regulations from NERC, which were loosely followed leading up to the disaster.

From the technical perspective, we learned that the maintenance and operation of generation stations and transmission lines needs to be constantly monitored and improved. Generation Stations cannot push synchronous generators beyond their rated capacity to counteract reactive loads, but beyond this, the maintenance of capacitor banks to support air conditioner loads are crucial. Proper maintenance of trees around transmission lines would have prevented several transmission lines from faulting as they sagged.

From the operational perspective, we learned the need for robust communication between different Control Areas, Reliability Coordinators, and the computer support teams working for each organization. Since the need for real-time data to support the contingency analyses is critical, any losses need to be immediately identified and communicated along the proper channels.

From the ethical perspective, since 100 deaths are attributed to the blackout, a lack of responsibility was the major cause. When issues occurred throughout the afternoon in August 14, 2003, FE personnel needed to communicate mounting problems, but failed to do so even though they could have. Average maintenance, even if not necessary for the day, could have prevented the loss of life in years ahead. Beyond this, backup systems which could pick up slack caused by human error were not present.