POWER SYSTEM & EQUIPMENT AND PERSONNEL SAFETY

2015

An Insight into System & Personnel Protection via Earthing

POWER SYSTEM & EQUIPMENT EARTHING

The Speaker

Today's speaker 'Muyiwa Falade is a staff of Shell Nigeria Exploration and Production Company (SNEPCo) based in Lagos, Nigeria. He is a trained and practicing professional engineer who has worked with SHELL for 26 years in various capacities and currently the Real Estate and Infrastructure Service manager for Nigerian territory.

'Muyiwa Falade has a first degree in Electronic and Electrical Engineering from the University of Ife, Ile-Ife, now Obafemi Awolow University (1986). A second degree in Project management from Villanova University, Villanova PA, USA (2003). He rose to position of Chief Electrical Engineer for Sub-Saharan African before being called into current senior management position. He has served the company on several assignments and in several countries, namely The Netherlands, South Korea, United States and Nigeria. Muyiwa is a member of Nigerian Society of Engineers (NSE) Port Harcourt Chapter, Member of Institute of Electronic & Electrical Engineer (IEEE), Houston Chapter, Texas, USA and a member of Project Management Institute (PMI), Houston Chapter, Texas, USA.

Muyiwa is married to Christine Ngozi Falade (An HR Practitioner) and blessed with four kids (Tobby, Leke, Tolu & Moyin)

One of my pet projects over my career is the development of a 100MW power for the Shell Oil & Gas Terminal on Bonny Island in Rivers State which was built in two phases (i) a 3 x 8.5MW plant and (ii) a 3 x 25MW plant and the Electrification of the Bonny Community.

The load forecast and Pictorial Illustration of part of project are shown overleaf.

Memoirs of a Past Project

1 – RESIDENTIAL AREA, MULTIPURPOSE GYM. SWIMMING POOL, ETC

2 – CENTRAL CONTROL BUILDING, MAIN OFFICE BUILDING & GOVERNMENT AGENCIES BLD.

3 – MARINE SERVICE AREA

4 – POWER STATION & FIRE WATER PUMP HOUSE

5 – CRUDE DEHYDRATION & STABILISATION FACILITIES

6 – CRUDE OIL STORAGE

7 – PRODUCED WATER TREATMENT FACILITIES

8 – EMULSION TREATMENT FACILITIES

9 – HP FUEL GAS & BONNY NAG PLANTS

10 – EXPORT PUMP HOUSE

Front View of Restaurant & Club House

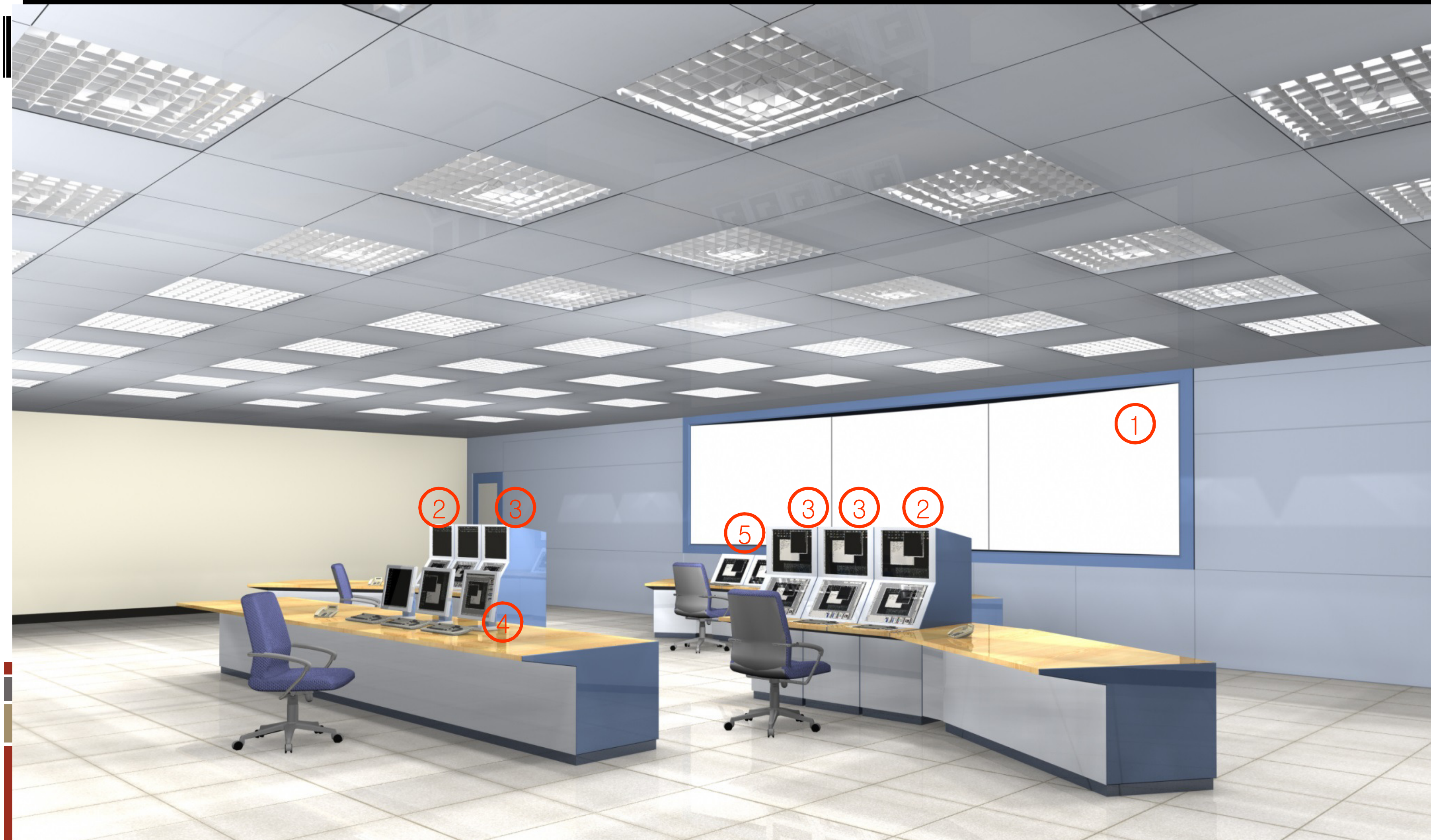
★ CAPACITY – 250 PERSONS

★ KEY FACILITIES :

* INDOOR GAME ROOM
* RESTAURANT & KITCHEN
* CONFERENCE ROOM / GENERAL PURPOSE HALL

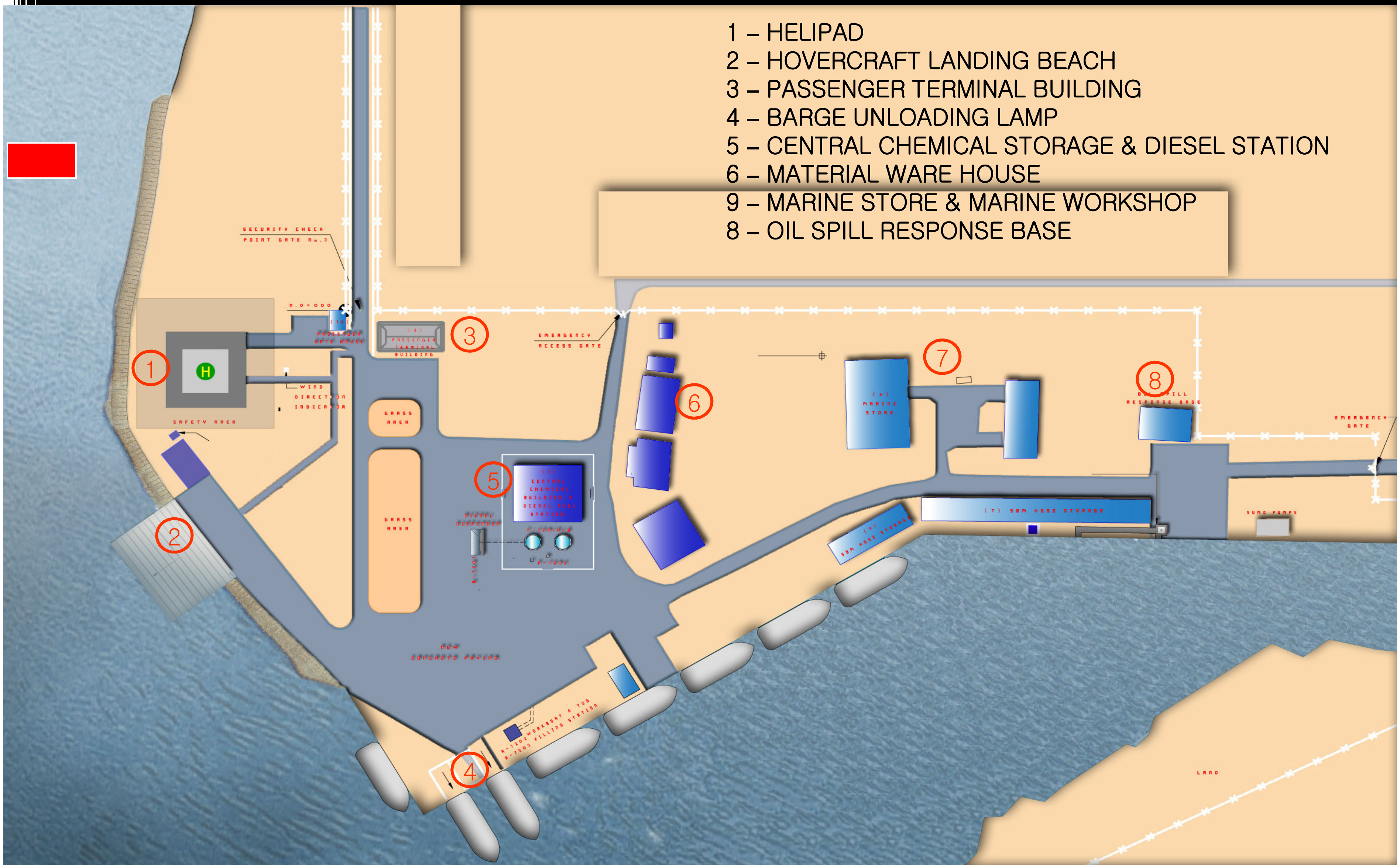
Front View of New Control Building

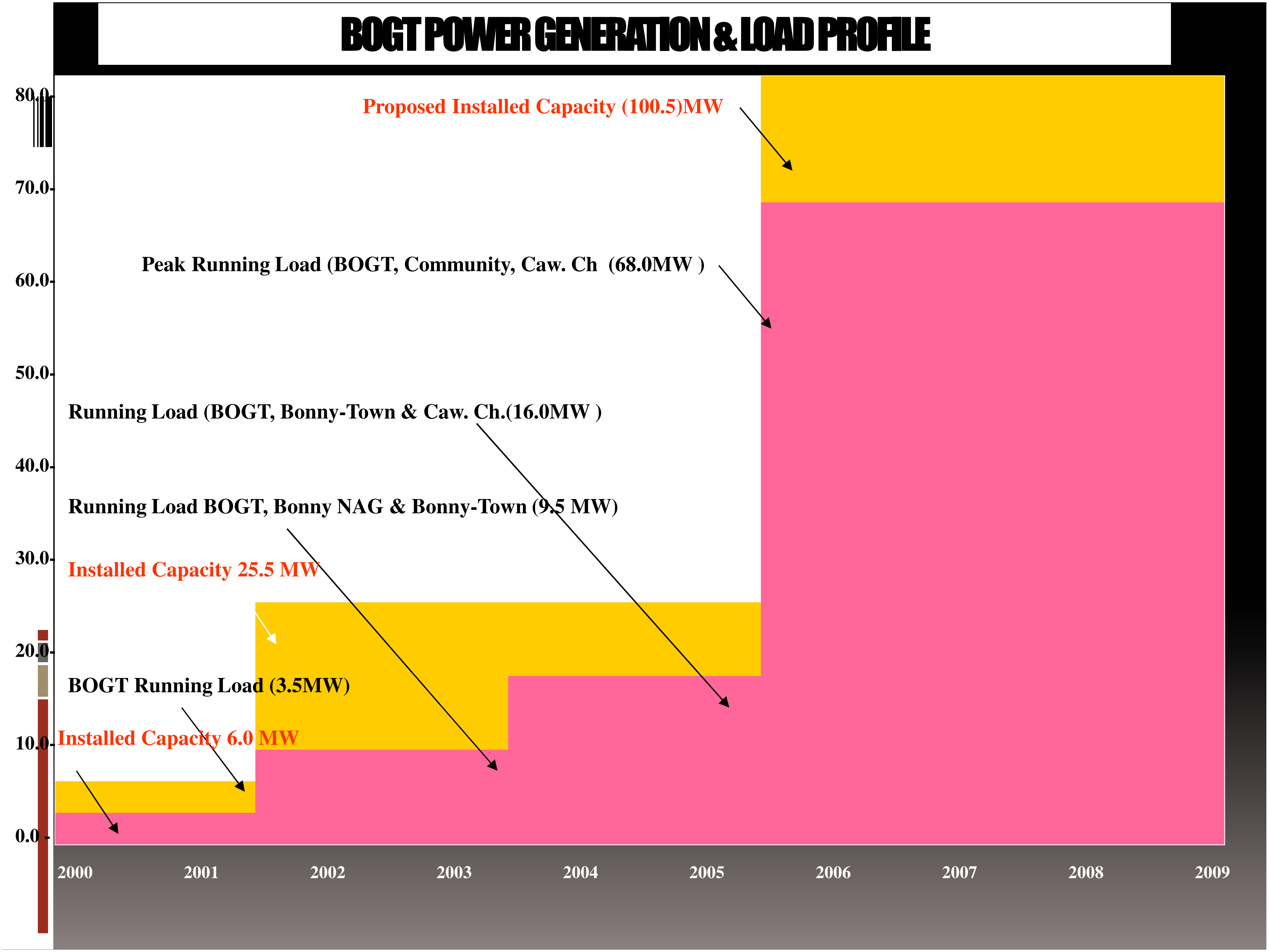
Inside View of Control Room



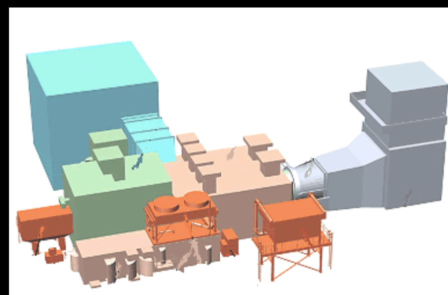
1 – STATE-OF-THE-ART WALL-MOUNTED PROCESS DISPLAY CONSOLE
2 – CCTV WORK STATIONS (FOR ENTIRE PLANT SURVEILLANCE)
3 – OPERATOR WORK STATIONS (FOR PLANT CONTROL AND MONITORING)
4 – METERING SYSTEM WORKSTATIONS (FOR CUSTODY TRANSFER)
5 – FIRE & GAS MIMIC CONSOLE (FOR FIRE MONITORING & CONTROL)

Layout of Marine Service Area




BOGT POWER GENERATION & LOAD PROFILE
Proposed Installed Capacity (100.5)MW
Peak Running Load (BOGT, Community, Caw. Ch (68.0MW)
Running Load (BOGT, Bonny-Town & Caw. Ch.(16.0MW)
Running Load BOGT, Bonny NAG & Bonny-Town (9.5 MW)
Installed Capacity 25.5 MW
BOGT Running Load (3.5MW)
Installed Capacity 6.0 MW
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

Electrical Power Generation & Distribution



SOLAR MARS T100-15000 (Existing)
8.5MW (@Site Rating) x 3 UNITS
TOTAL CAPACITY : 25.5[MW]

HITACHI H-25, 25MW RANGE (New)
3 UNITS (NORMAL:2 + SPARE:1)
TOTAL CAPACITY : 75[MW]

BONNY TERMINAL

LOAD : 41[MW]

BONNY TOWNSHIP

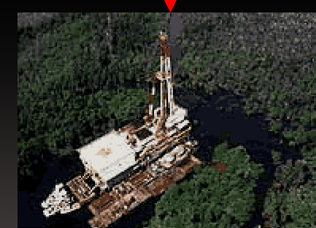
LOAD : 8 [MW]

BONNY NAG

LOAD : 0.6 [MW]

BONNY Development

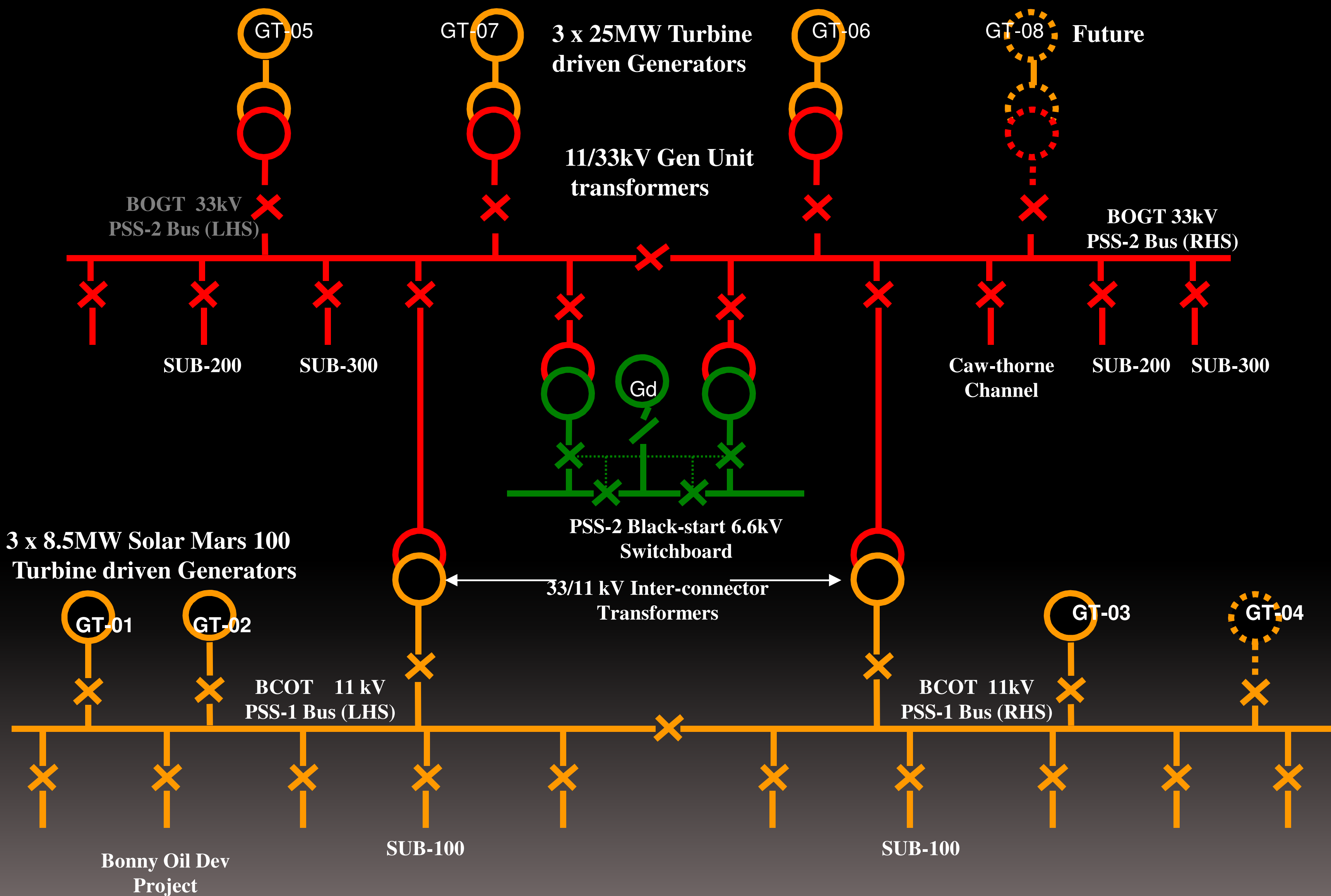
LOAD : 3.5 [MW]



Cawthorne-Channel

LOAD : 8 [MW]

BTIP POWER SYSTEM - BONNY NODE



Power System & Equipment earthing and Personnel Safety

Overview of Earthing Systems

The Earth:

- **Mass of Earth, core of the earth (land and bottom of underwater).**
- **Reference point for electrical circuit voltages. (Theoriticaly Zero Potential)**
- **Common return path for electric current.**
- **Direct physical connection to the Earth and Earth Electrode.**

Earthing System groupings:

- **System Earthing**:- Intentionally electrical connection of power system to the mass of earth.
- **Equipment Earthing/Bonding**:-

  Connection of non-current-carrying metallic chassis of above ground equipment to earth.

Why Power System & Equipment Earthing?

- An anchorage of power system to prevent voltage swings under fault conditions (Transient voltages, arcs, static electricity, lightning strikes, contact with higher potentials)
- Earth connections will dissipates, discharges stray potentials and limit the voltage rise in earthed system.

Overview of Unearthed systems

- Neither the HV nor the LV systems are earthed

Demerits

- Under fault conditions conductors becomes charged to significant potential.
- System risks insulation breakdown of sub-systems and devices
- Risks short circuit to earth e.g. HV/LV windings, breakdown of insulation on transformer
- Risks Internal Arcs (Flashes & Blast) of Sub-systems, Explosions, Fires, Hot Oil discharge
- Exposure of Electrical Personnel & Operators to Electrical Incidents
- Line to line, Full three phase or Dead bolt short circuit on a second Earth fault

Merits:-

- No System failure at first earth Fault, business can be sustained, take time to clear fault.

Special Consideration:-

- An unearthed system cabling and winding insulation must be specified for full Line to line Voltage, particularly more significant in HV System voltage where it becomes increasingly important and costly

Vector & Earth Fault Analysis –Unearthed System

Fig 1a, shows a HV generator or transformer with 3 output terminals R, Y, B completely unearthed.

Figure 1a bottom. Shows the voltage vector diagram with the three line to line voltages V(RY), V(YB) and V(RB) forming a closed triangle. The point of zero potential does not appear on the diagram because there is no reference to Earth. The voltages can therefore float freely. The vector diagram therefore only shows their mutual relationship between the lines and none to earth whether system is star or delta connected.

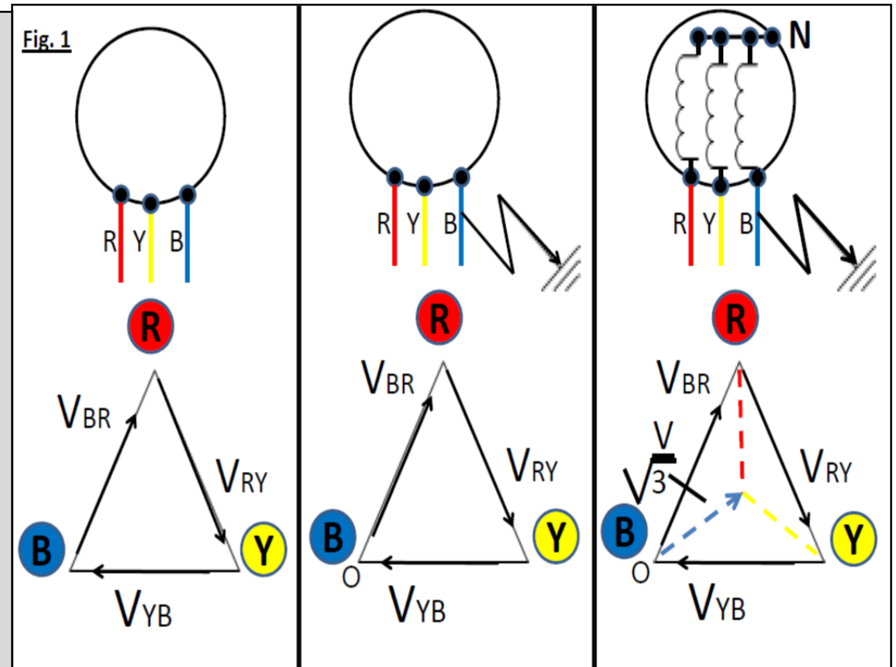


Fig 1a. NORMAL

Fig 1b. EARTH FAULT

Fig 1c. NEUTRAL VOLTAGE WITH EARTH FAULT

Fig 1b shows a solid earth fault established between the blue phase and the earth, the resultant vector diagram is unaltered, Point B on the vector diagram only becomes equalized with origin O at zero potential. However points R and Y retain their positions relative to B as before. Although B is now at the origin, the actual voltage to earth on the red phase is <u>OR</u> which is equal to line to line voltage V(BR) and actual voltage of the yellow phase is <u>OY</u> and is equal to line to line voltage V(YB).

In an unearthed system, an accidental grounding of one of the lines will cause other phases to take on line to line voltages between the phases and earth be it generator or transformer feed system

Overview of Earthed Systems

- Prevent system voltage from floating freely, usual practice on a Shell installation to tie Neutral permanently to earth.
- For symmetry purposes we chose to anchor the neutral or star-point of the supply network which could be a generator or a transformer,
- For it to work the system has to be star connected.

Merits:-

- No system part can be at higher potential to earth than system nominal voltage.
- With proper design provide pre-determined voltages and fault currents.
- Can select High or Low resistance earthing depending on system requirements.
- High resistance/Impedance will tolerate a first fault without interrupting operational services hence preferred in Shell Refineries.
- Low resistance will ensure adequate fault current to operate protective device.

Demerits/Special consideration:-

A second ground fault must be tripped by protection relay otherwise a multi- phase short circuit will occur with more severe.

Options for Resistance Earthing

- **Low-Resistance Earthing Systems** use a neutral earthing resistor (NER) to limit the fault current to 25 A or greater.
- Low resistance grounding systems will have a time rating (say, 10 seconds) that indicates how long the resistor can carry the fault current before overheating.
- A ground fault protection relay must trip the breaker to protect the circuit before overheating of the resistor occurs.

- **High-Resistance Earthing (HRE) Systems** use an NER to limit the fault current to 25 A or less.
- Continuously Rated and designed to operate with a single-ground fault in place. This means that system will not trip on the first ground fault.
- On an HRE system, a sensing resistor is used to monitor system continuity. If an open-circuit is detected (e.g. due to a broken weld on the NER), the monitoring device will sense voltage through the sensing resistor and trip the breaker.
- Without a sensing resistor, system continues to operate without fault protection (an open circuit would mask the earth fault) and transient surges may occur.

Vector & Earth Fault Analysis – Earthed System

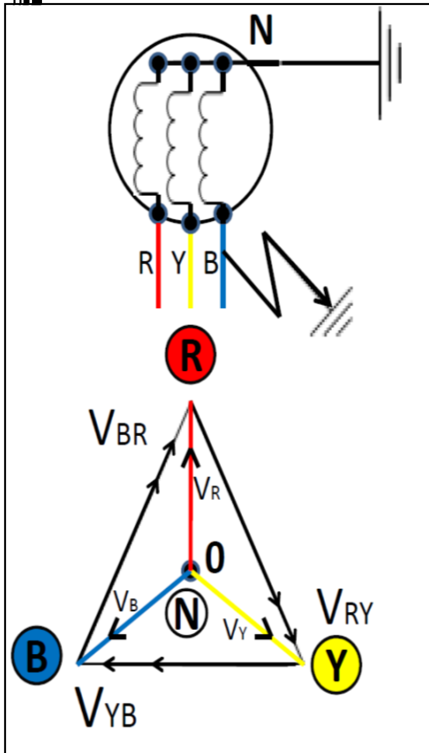


Fig 2a. NORMAL

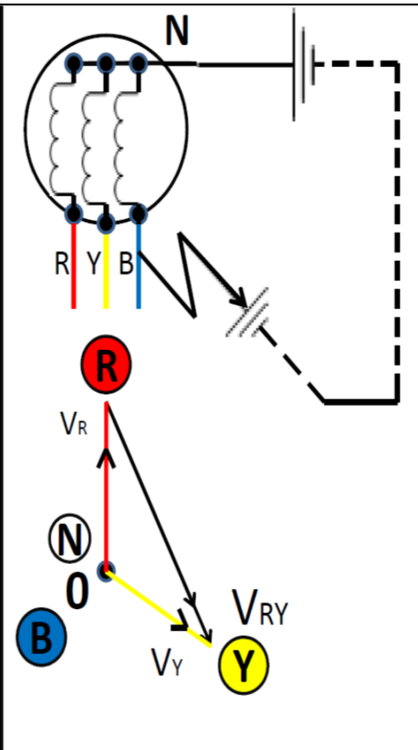


Fig 2b. WITH EARTH FAULT

This arrangement has a further advantage. At the bottom of figure 2a is the vector diagram of such a system, the three vectors NR, NY and NB are 120 degrees apart and represent the three phase voltages V(R), V(Y) and V(B) relative to the neutral point N. Since the neutral point N is earthed, it is the same as the origin O. The three line-to line voltages V(RY), V(YB) and V(BR) are represented by the vectors RY, YB and BR.

Since the origin O is the neutral point, the voltage to earth of the three terminals R, Y and B can neither exceed their phase voltages V(R) = V(Y) =V(B), which is only one over Root 3 of the line to line voltage.

Where one line say Blue is accidentally earthed, the situation in figure 2b will result. The blue phase will be completely short circuited, since both ends of B and N would be at earth potential phase voltage V(B) will disappear and point B moves to O,

The other phases V(R) and V(Y) will not be affected (unlike the unearthed system), they would remain at Line to line voltage divided by Root 3 (i.e. Phase Voltage) just as before the fault developed.

So whereas in an unearthed system any line can rise to full line to line voltage in the event of an earth fault on a line, in an earthed system the voltage to earth of the lines cannot exceed the phase voltages approximately 0.58 of line voltage. Therefore an earthed system can use a lower level of insulation thus less costly to make operational safe than an equivalent unearthed system with the same line voltage. Even safer if uniform insulation is applied.

Impact of Earth Fault Current – Earthed System

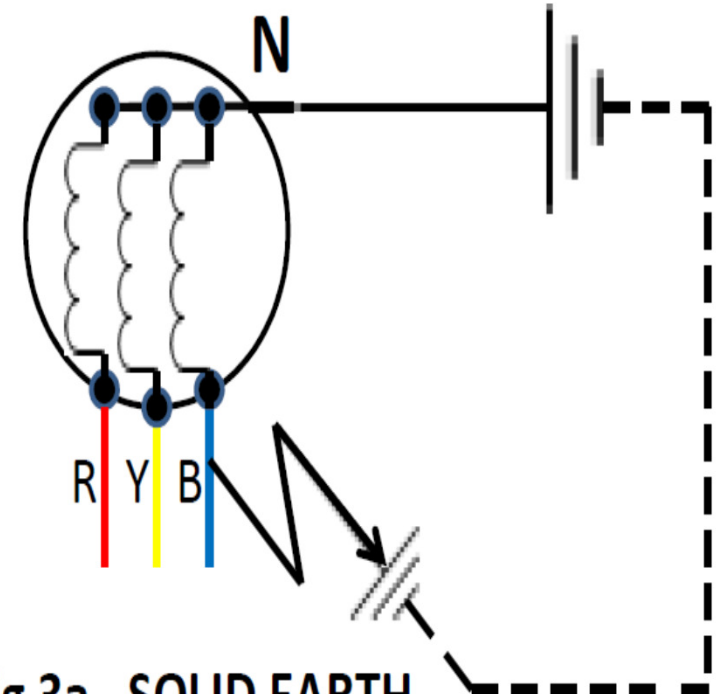


Fig 3a. SOLID EARTH

A solidly earthed system is shown in figure 3a

Where an earth fault develops on the blue phase, It is clear that a fault current will flow between the blue phase and the neutral point. The fault current is only limited by the Blue phase winding impedance; such fault current could initially be many times the normal design full load current of the generator and if sustained could permanently damage the generator by resultant over heating of winding insulation or by mechanical strain.

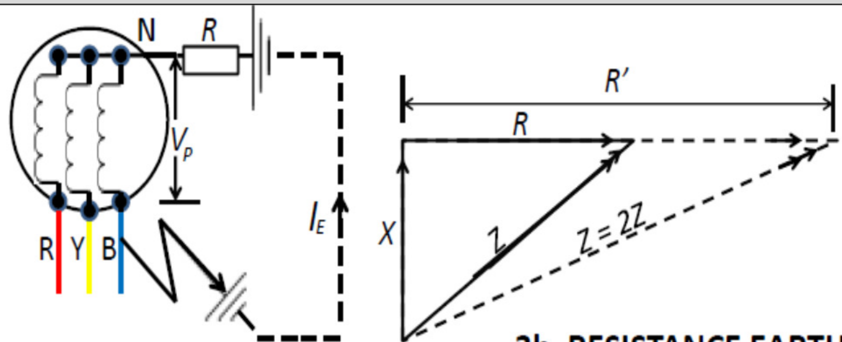
A further hazard is at fault point itself, where an arching earth is likely, the fierce short circuit current could cause intense local heating (hot spot) with attendant risk of escalating into an arc-flash and likelihood of fire.

This high fault current is a significant disadvantage of an earthed system, this would not occur on a first line-earth fault in an unearthed system. In order therefore to avoid the impact of large fault currents and cost of designing systems to withstand faults prior to protection relay action, earth fault limiting devices were introduced to power system design, particularly at HV. So solid earthing is practically restricted to LV system where the fault is limited by the capacity of the alternator or Transformers.

Notable fault limiting devices are resistance (NER) and transformer or Impedance earthing of power system. Beyond devices there is also the need to consider single or multiple devices in a multi-generator network.

Fault Analysis – Single Resistance Earthed System

Fig 3b shows where the generator is earthed via a current limiting, heavy duty, short time rated resistance (NER) of low ohmic value. It can be seen from the figure that in the event of a line to earth, the short circuit current in the earthed phase in now not only limited by the winding impedance but also by the introduced earthing resistance. Since generator impedance is almost wholly reactive (X) it adds vectorally to the resisitance (R) to produce an impedance (Z) which limits the fault current as shown in the figure 3b.



3b RESISTANCE EARTH

With a typical 15MW generator set on a Shell platform the resistance value calculated may be as low as 10ohms which with a typical generator internal reactance of 0.63 ohms gives an earth fault current pf 400A, equivalent of 25% of full load currents. Usually the resistance value may become so much greater that the generator Reactance (X) that it could be neglected in which case Z = R.

Where the value of the resistance is correctly chosen, the earth fault current can be limited to:-

(i) Normal full load current of the generator
(ii) 50% of nominal full load current or
(iii) 25% of the nominal full load current

Limiting the fault's capacity to damage the machine and interconnections as well as costing less for a robust and well protected system.

Clearly it is desirable to limit earth fault current as much as possible, however sufficient current must be available to trip the protective relays.

Depending on the system design objective the resistance can be increased further as shown in the dotted line if figure 3b.

Sample Sizing Calculation - Single NER

Example

An 18MVA, 6.6kV star-connected generator is provided with a neutral earthing resistor. What must be the value of this resistor be if it is to limit the earth-fault current of one phase to one-half of the full-load current? (The reactance of the generator winding may be neglected.)

First calculate the full-load current I_F.

$$I_F = \frac{kVA}{\sqrt{3}kV} = \frac{18\ 000}{\sqrt{3} \times 6.6} = 1\ 575\ A$$

Fault current (I_E) is to be limited to half this:

$$I_E = 1\ 575/2 = 788\ A \quad \text{....} \quad (i)$$

In the Figure 3(b), the fault current I_E is given from the fault circuit whose EMF is the phase voltage V_P, where $V_P = V_L/\sqrt{3} = 3.81kV$ Ignoring the generator's phase reactance X, the fault current is given by Ohm's Law:

$$I_E = V_P/R \quad \text{Or} \quad R = V_P/I_E$$

$$\frac{3.81 \times 1000}{788} \text{ from (i) above} = 4.84 \text{ ohms}$$

Options of Low & High resistance Earthing/Grounding

As a rule of thumb, low-resistance earthing systems use an (NER) to limit the fault current to 25 A and above. Low resistance grounding systems will have a withstand time rating (say, 10 seconds) before damage due to overheating. An earth fault relay must trip the circuit breaker before overheating of the resistor occurs.

High-resistance earthing (HRE) systems use an NER to limit the fault current to 25 A or less. They have a continuous rating, and are designed to operate with a single-ground fault in place. This means that the system will not immediately trip on the first ground fault. If a second ground fault occurs, a ground fault protection relay must trip the breaker

High Resistance- Single NER cont-d

On an HRE system, a sensing resistor is used to continuously monitor system continuity. If an open-circuit is detected (e.g., due to a broken weld on the NER), the monitoring device will sense voltage through the sensing resistor and trip the breaker. Without a sensing resistor, the system could continue to operate without ground protection (since an open circuit condition would mask the ground fault) and transient over-voltages could occur.

Merit of HRE is the ability to accommodate the first earth fault without tripping hence patronized by Shell Refineries to prevent Power supply outage as a result of a first earth fault.

Multiple Generator Network Earthing

Principle:

Ideally a Network of several parallel generators should only be earthed at one point to prevent circulating currents and harmonic currents flowing within the generators causing unnecessarily overload. So ideally only one Earthing switch should be in place

In practice however most generators are now designed to accept such currents and the links are left closed in all machines. For design engineers, this must be specified as part of generator specification during requisition. See figure 4. Links can be monitored by a logic system to give alarm whenever the system floats due to link of a generator not being in service.

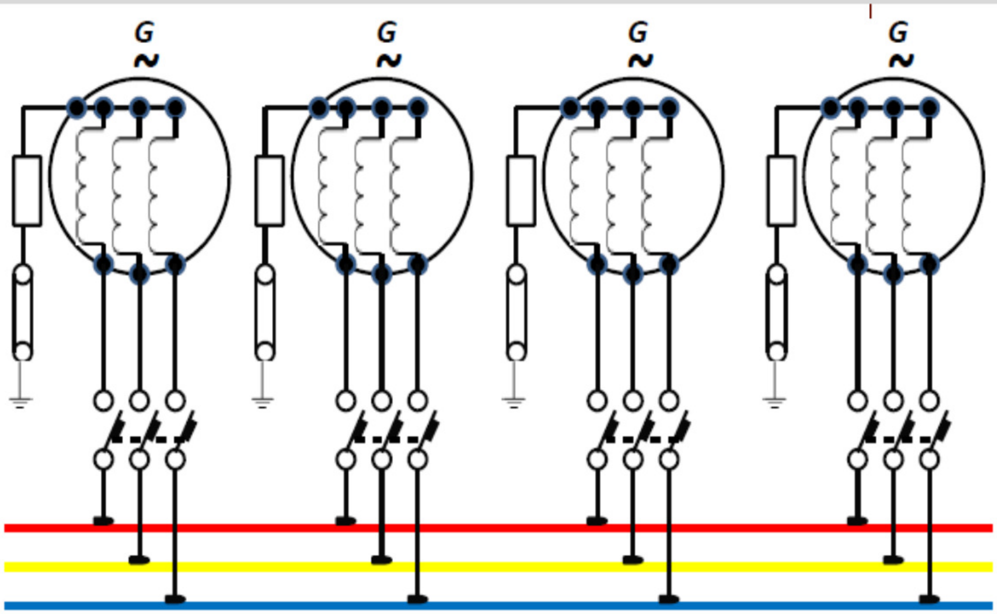
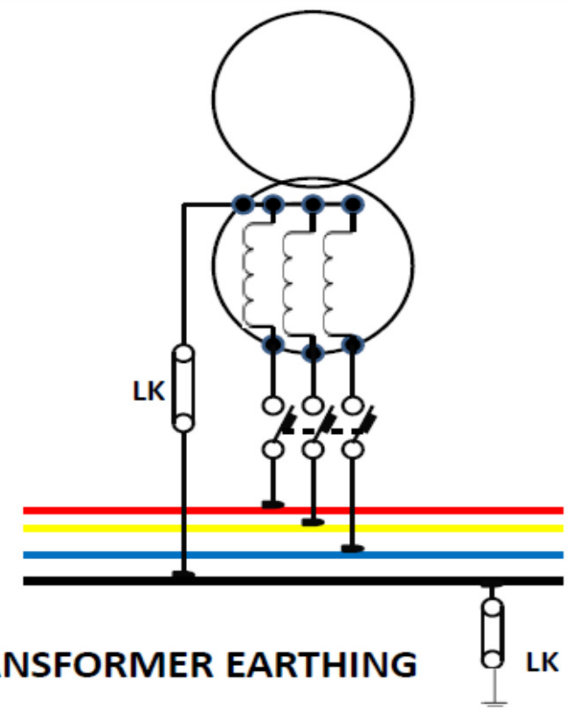


Figure 4. MULTIPLE EARTHING OF GENERARTORS



ig 5. TRANSFORMER EARTHING

Transformer Earthing

Whereas resistance earthing of HV generators is common throughout Shell platforms, the secondary neutral points of all transformer are solidly earthed, either at the transformer itself or more usually through the neutral bus-bar of the LV switchboard which it supplies. See figure 5.

There is then no resistor to limit the earth fault current.

The reason for this is twofold; First the secondary winding of the power transformer are in any case robust and can withstand better than an HV generators the full earth fault currents allowed by a solid earth. The key benefit here is that there is sufficient fault current to trip the earth fault protection relay e.g. 51G, 51T.

Secondly, the amount of energy available to be released at the fault by an arching earth is much less than on the HV side, where it comes straight from the terminals of the generator. This factor is therefore of less importance.

Earthing of Fixed Metallic Equipment

OVERVIEW

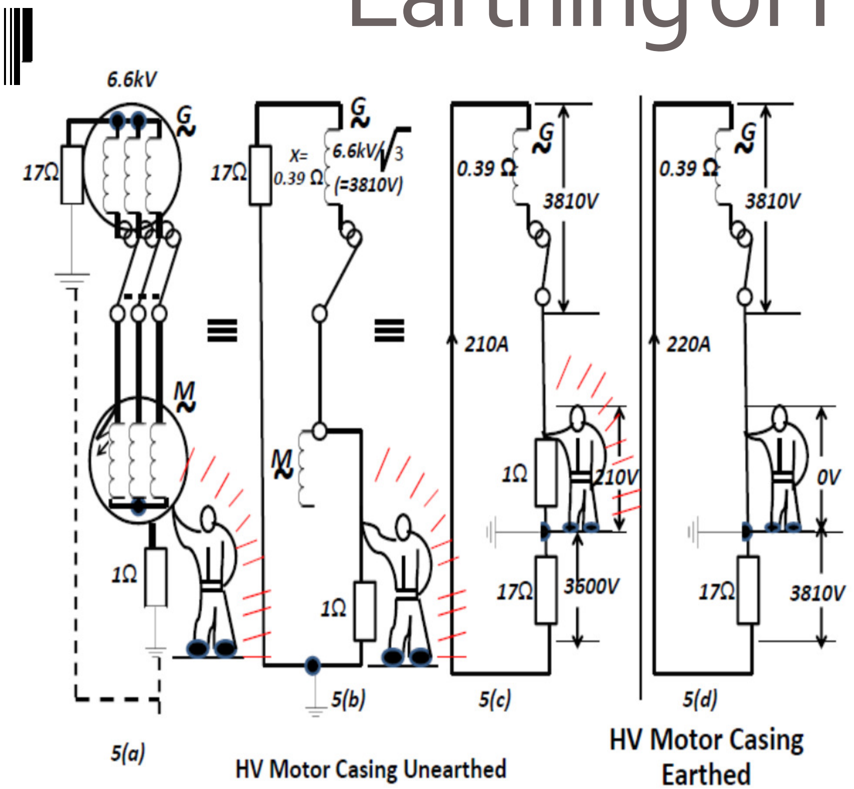
All metal parts of Electrical Equipment and all Metallic parts of process plant must be securely earthed to the offshore installation frame or earth ring of Onshore Installation:

- To prevent danger of electric shock resulting from the outer casing of electrical equipment becoming live through an internal fault e.g. Insulation breakdown.
- To avoid risk of explosion by sparking resulting from the vessel and pipe work of process plant becoming electro-statically charged by movement of the hydro-carbon fluids within them.
- To gradually discharge bound charges in Hydrocarbon Fluid to prevent Ignition.

These risks are avoided by earthing apparatus or process vessels.
Figure 5 (a) shows a typical item (a motor) fed from a 6.6kV high-voltage circuit. The generator star-point is earthed via an NER taken in this example as 17 ohms.

It is assumed that an internal fault has developed in one phase of the motor, resulting in that phase being short-circuited to the motor case. It is further assumed that the motor case is not specially earthed and that poor contact (perhaps due to paint) exists between the motor feet and the bedplate, resulting in a contact resistance of 1 ohm. The situation is then as in Figure 5(a), and a man standing on the ground and touching the motor case will get a severe shock resulting from the voltage due to the earth-fault current, whose route is shown in heavy line

Earthing of HV Motor Casing

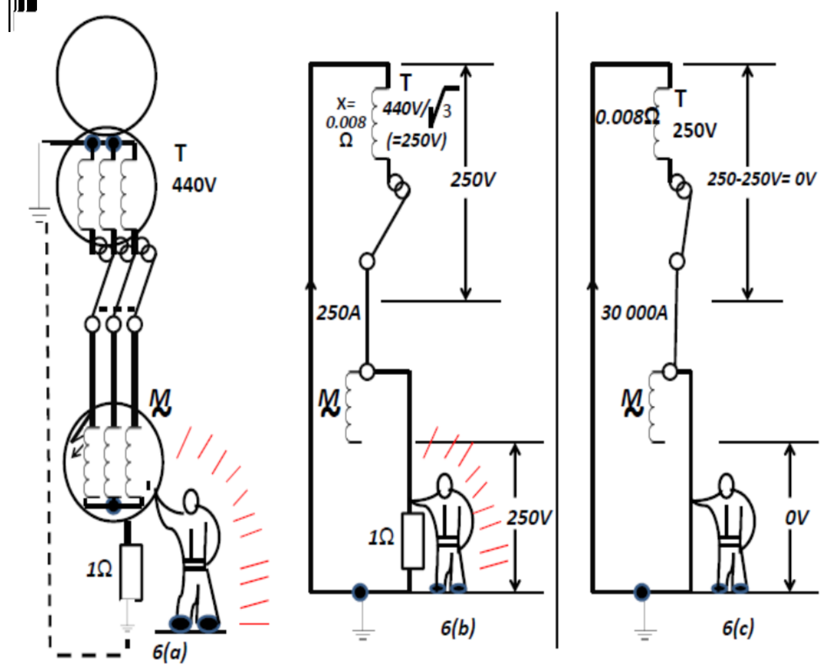


The earth-fault current increases due to the reduction of the total circuit resistance from 18 to 17 ohms, but no voltage now appears between the man's hand and feet, and he is protected from shock. (Note that the generator reactance, in this case 0.39 ohms, hardly enters the calculation, since it is negligibly small compared with the 17-ohm resistance of the NER)..

Fig 5(b) is a simplification of the electric circuit of Fig 5(a) showing only the fault phase and the resulting current loop. Figure 5(c) is a further equivalent in which the 17-ohm NER and the 1-ohm contact resistance act as a potentiometer. The earth-fault current is limited to 210A by the combined 17-ohm and 1-ohm resistances. This current, flowing through the 1-ohm contact resistance, causes a 210V difference between the man's hand and feet enough to cause a severe shock, especially if the deck were wet. The voltage felt by the man is determined by the 1:17 potentiometer ratio and is in this case, 1/18th of the total phase voltage 3.81kV (=6.6/RT3). If the contact resistance were higher than 1 ohm, the shock voltage would be greater.

Conversely, if the contact resistance were less, the voltage would be lower. If the motor case were solidly bonded to the platform frame by a strap of negligible resistance, the contact resistance would be shunted and would become zero. The situation is then as in Figure 5(d), where the 1-ohm element disappears and the full phase voltage of 3.81kV appears across the 17-ohm NER only.

Earthing of LV Motor Casing



LV Motor Casing Unearthed

LV Motor Casing Earthed

In Figure 5(c), the motor has been solidly earthed and the 1-ohm contact resistance completely shunted, so that it appears from the figure, leaving the fault current to be limited solely by the reactance of the transformer winding. It will rise to very high figure of some 30 000A, but no voltage now appears between the man's hand and feet, and again he is protected from shock.

A similar situation occurs with a low-voltage motor, as shown in Figure 4.2, except that all LV system neutrals are **solidly** earthed, without any NER. Figure 5(a) shows a situation otherwise similar to the high-voltage case, with a phase-to-case fault in the motor, together with a poor contact resistance of 1 ohm between motor and platform.

Figure 5(b) is the equivalent circuit for the faulty phase. With a typical 2 000kVA, 440V transformer the 1-ohm contact resistance will limit the fault current to about 250A (again ignoring the very small transformer reactance, typically 0.008 ohm), and this will appear as a 250V difference across the 1 ohm between the man's hand and feet – again enough to cause a severe shock (V=IR).

Electrostatic Earthing of Process Plant

All process and similar structures throughout our onshore and offshore installations, and their associated pipework and tanks are solidly bonded together and earthed by bonding to the structural steel mass of the platform or the earth ring onshore.

The flow of hydrocarbon gases or oil through pipe work and containment vessels can give rise to static charges on the inside and the outside of those pipes or vessels, appearing as very high potentials. They will discharge to earth, to people or to each other on contact, or even without contact usually as a high energy spark. In a hazardous area and in the presence of gas this could cause a major explosion.

Earthing of such process plants and similar structures is therefore necessary:

- To prevent build-up of static charges on the plant with consequent risk of a spark.
- To prevent corrosion due to those static charges.
- To slowly discharge bound charges in Hydrocarbon Fluid to prevent Ignition

The bonding & earthing of all pipe-work and vessels to which it is fitted is important. Differences of static potential in two connected pipes could lead to arching, sparking and even corrosion across flanges and joints. The bonding of such unions is an important part of the structure earthing system. Therefore Earthing and bonding of all vessels and pipework ensures that such static charges do not build up and are carried away (discharged) as fast as they form.