CASE STUDY ON DESIGN AND TESTING LOW VOLTAGE ELECTRICAL MAIN SWITCHBOARD FOR MASJID ISMAILI AT KOTA BHARU KELANTAN

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ABSTRACT

An Electrical Main Switchboard (MSB) is a device that directs electricity from one source to another. The role of a switchboard is to divide the main current provided to the switchboard into smaller currents for further distribution and to provide switching, current protection and metering for these various currents. The Electrical Main Switchboard is designed and installed at high risk buildings such as huge office buildings, industrial parks or commercial buildings and need to be tested by competent personnel or agency which have to comply with the applicable standard, working practice which is adopted by the authorities. A well planned in design and installation dramatically improves safety and reduces downtime of fault. This paper will discuss the principles of design, installation and testing of electrical Main Switchboard (MSB) used in high risk buildings especially with incoming high voltage supply from Sub-Station at 415 kV. The main idea of this discussion is focused on the electrical design and installation devices such as sizing of Molded Circuit Breaker (MCCB), miniature Circuit breaker (MCB), Air Circuit Breaker (ACB) and the sizing of the cable size installed in the system. At the last part of this paper, the installed devices on MSB will be tested and verified through visual and electrical inspection and electrical test. As The results showed that the MSB unit passed all the tests conducted by third-party as required by the authorities. Therefore it compliant to installed in the related building and is guaranteed to be safe for users.

Keywords: Low Voltage, Main Switchboard, Design, testing

1. Introduction

An Electrical Main Switchboard is a apparatus that is used to direct electricity from one source to another. It is an assembly of panels, each comprises of switches that allow electricity to be redirected. The National Electrical Code (NEC) defines a switchboard as a large single panel, frame, or assembly of panels which are mounted, on the face, back, or both, switches, overcurrent and other protective devices, buses, and usually instruments (Electric Switchboard, 2013). The role of a switchboard is to divide the main current provided to the switchboard into smaller currents for further distribution. It is also provide switching, current protection and metering for these various currents. In general, switchboards distribute power to panel boards, control equipment, and ultimately to system loads (Tenaga Nasional Berhad,2011).

The Electrical Main Switchboard is designed and installed at high risk buildings such as huge office buildings, industrial parks or commercial buildings and need to be tested by competent personnel or agency who have to comply with the applicable standard, working practice adopted by the authorities. In Malaysia this practice has to comply to the standards fixed by Tenaga Nasional Malaysia (Ehsan) (JKR, 1999), Jabatan Kerja Raya Malaysia (IEE-BSI, 2004) as well as standards adopted by the Institute of Electrical and Electronic (IEE) Installation Regulation (Wiley-Blackwell, 2008; Brian Scaddan, 2004; Willem Maes,2014). This is to prevent and protect consumers from fatal errors especialy death or serious injuries. Some of the faults or power failure to the load are caused by the lack of design and installation of MSB such as overload, earth fault or leakage, faulty in installation, insufficient power supply and etc (Borman J. B.,1991). These will cause tripping, burning and even fatal error to equipment or people (Rogers,1984). Therefore, a well planned in design and installation will dramatically improve safety and reduces downtime of fault.

This paper will discuss on the principles of design, installations and testings of Electrical Main Switchboard (MSB) used in high risk buildings especially with incoming high voltage supply from Sub-Station at 415 kV. In this situation their respective building have to be protected from any failure or disturbance of power by the electrical distribution system especially the MSB. The main idea of this discussion is centred on the electrical design and installation such as sizing of Molded Circuit Breaker (MCCB), miniature Circuit breaker (MCB), Air Circuit Breaker (ACB), and sizing of the cable size installed in the system. This paper is written as a case study of the project conducted by Mechanical and Electrical Consultants company to one of their projects at Masjid Ismaili in Kota Bharu, Kelantan. In the last section of this paper, the design and installation of MSB will be tested and verified through visual and electrical inspection and electrical test by a third-party company. The results it showed that the MSB unit passed all the conducted tests as required by the authorities. Therefore it is compliant to be installed to the related building and is guaranted to safe for user.

2. Electrical Design Methodology Of The Electrical Main Switchboard.

The purpose of the Main Switchboard (MSB) is to divide the current or supply to the dedicated buildings with sufficient demand and most importantly is to protect the building from causes serious fault to the equipment and personnel. Based on this role of the MSB, the following sections will be discussed and focused on the designing of the system to protect the apparatus or personnel as well as to supply the current for present and future demands.

2.1. Components/Devices of The Electrical Main Switchboard.

Electrical Main Switchboard is very an important device that serves to protect electrical hub of the electrical power source delivered to a building. It receives electrical power supply as well as controls the power supply, distributes the power supply and protects the power supply. The components such as air circuit breaker (ACB), surge protection, IDMT EF/OC, MCBs, bus bar, current transformer and other accessories such as ampere/volt Meter, capacitor bank and etc are installed in the electrical switchboard. These components operate automatically or manually depending on the their purposes. In addition it is to protect the load with open and break circuit especially with ACB, MCB, and EF/OC devices. Vast knowledge design, installation as well as experience about the main switchboard and it components would ensure the continuity of the power supply with less disruptions to the daily operation.

The following rules of design have to be implemented in order to facilitate the assembly and especially the maintenance of the installation. The switchboard must be designed to have a clearly visible separation between the 3 following zones such as devices installation compartments, bus bars mounting and Incoming and outgoing cables connections. Bus bars are a bank of flat strips with copper or aluminum, to which the switchboard devices are connected. These switchboards carry large currents through bus bars and are supported by insulators (Bhagawan Prasad,2013). There are 2 types of bus bars i.e. horizontal and vertical bus. Figure 1 shows the layout of component in three zones (Jean-Pierre Thierry & Christophe Kilindjian,1996); Eaton, 2013).

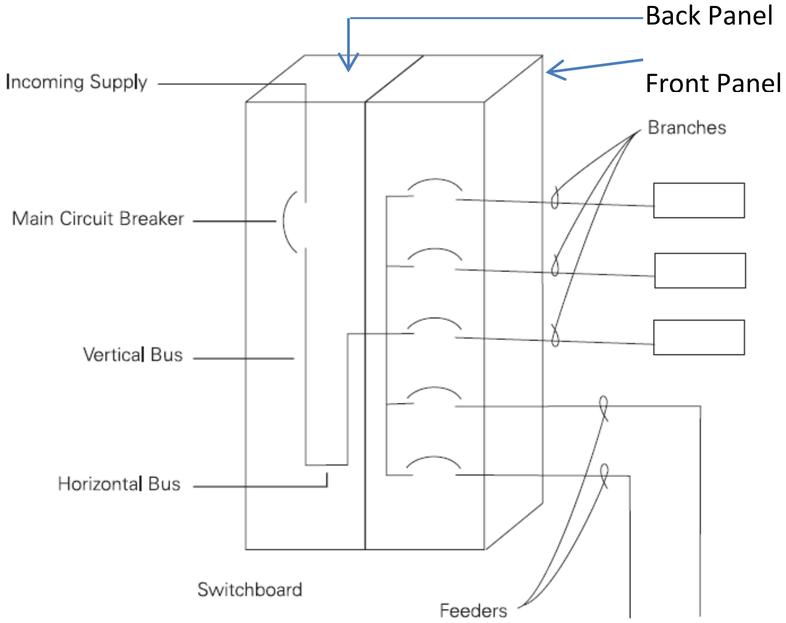


Figure 1: Layout of Switchboard Structure

Devices/components are mounted on the front side of the switchboard. These include protective devices, such as circuit breakers (MCCB/ACB) and disconnect switches, which can be covered by a trim panel. These devices are mounted to the bus bars using straps connected to the line side of the devices.

The protective electrical components such as MCB or Air Vacuum Breaker (ACB) need to be designed to suit with the rating values respective of the load connected to the MSB. Another component that should be considered during the design of MSB is the cable size for respective MCB or ACB based on current rating flow through these components. The rating for each MSB or ACB and cable size for respective current rating will be discussed in the next part of this paper.

2.2. Electrical Design of Main Switch Board (MSB)

The two main protective devices that should be considered during design of MSB for residential or commercial buildings are Main Circuit Breaker (MCB) and Air Vacuum Breaker (AVB). Instead of considering MCB/AVB current rating, the size of cable installed to MSB and the load in the system should be considered. Figure 2 shows the picture of compartment devices installed in MSB.

Figure 2: Compartment devices installed in MSB

2.2.1 Electrical Design for Main Circuit Breaker (MCB) and Air Vaccum Breaker (AVB) Rating.

The designing of the MCB and AVB rating referred to the load install in the system. For discussion, Table 1 listed the load of maximum demand (MD) installed to the MSB of Masjid Ismaili at Kota Bahru Kelantan with the current (A) and MCB/ACB ratings determined.

Table 1: MCB/ACB Rating Based on Current

Item/Load	Maximum Demand (MD) (kW)	Current (A) (MD x 1.74)	MCB/ACB rating (A)
A	79.10	137.64	200
B	273.50	475.89	600
C	101.30	176.262	200
D	19.00	33.06	50
E	195.00	339.3	500
F	15.00	26.1	50
G	2.00	3.48	30
H	35.29	61.40	100
I	10.59	18.43	50
J	15.00	26.1	50
K	15.00	26.1	50
Total	**760.78**	**1323.78**	**1500 (ACB)**

Before the maximum demand (MD) is calculated the Total Connected Load (TCL) should be decided for the particular area or sub-circuit in the project. TCL is define as the mechanical and electrical load (in kW) that is connected (or to be consumed) for that particular area. The formulation of Total connected load is summarized in the form as equation (1). As a result the maximum demand (MD) for each circuit or connected load is defined as equation (2). The Maximum Demand (MD) is the total kW that actually contributes the total power once after applying the diversity factor (DF) based on the Total Connected Load calculated for each device (Steward W.E. and Beck R.A.,2010; Wong Chin Chong, 1991; Sufi Shah Hamid Jalali, 2014). The maximum demand is usually measured in units of kilowatts (kW) or megawatts (MW).

TCL = Quantity (Nos) x Load (Kw) (1)

DM = TCL x Diversity Factor (2)

When an installation is to be supplied directly from a Medium Voltage (MV) or Low Voltage (LV) the nominal full-load current (I_n) on the LV side of a 3-phase will be defined as equation 4 (Steward W.E. and Beck R.A., 2010; Wong Chin Chong, 1991).

$$I_n = \frac{P_a \times 10^3}{u\sqrt{3}} \quad (3)$$

Where, P_a = kVA rating of the transformer; U = phase-to-phase voltage at no-load in volts (237 V or 415 V); I_n is in amperes. By simplifying the equation (3) for U = 415 V (3-phase load) with P_a in kWatt, then equation 4 will be introduced.

$$I_n = \text{Kwatt} \times 1.74 \quad (4)$$

The equation 4 shown the nominal full-load current I_n for respectively load in Ampere. Based on the equation (4) the total load current occupied by installed devices to MSB/ACB as listed in Table 1 will be determined. For example the item/load A as shown in Table 1 with MD 79.10 kW as the calculation of current (MD x 1.74) is 137.64. Then from the rule of thumb, the nearest of the suitable MCB rating is 200 Ampere is required to protect the circuit load A. In addition, the same method of calculation will be used for other loads as listed in Table 1.

2.2.2. Calculation of Cable size

In designing of the cable size conductor, the designer should considered that the cables size should be large enough to carry the maximum expected load current without exceeding the temperature limit appropriate to the insulating material involved. There are several parameters to be considered when determining the current-carrying capacity of the cable such as the conductor material, the insulator material, the ambient temperature and the method of installation, including grouping with the cables of other circuits. Based on the parameters above, there are three current values which have to be coordinated; Fuse Circuit breaker (I_n), Load (I_b) and conductor/cable rating (I_z). Since the overcurrent protective device is required by both to carry the design current I_b ccontinuously and to operate in an overcurrent before the conductors or any surrounding insulations are in way impaired. The following mathematical co-ordination must be satisfied by the circuit design as $I_z \geq I_n \geq I_b$ (Wong Chin Chong, 1991; Paul Cook, 2008).

Therefore, to size the live conductor of circuit, we need to follow the written steps. First, determine the design current I_b (ie. The maximum steady current to be carried), secondly select the type and nominal rating of overcurrent protective device, I_n), thirdly apply the relevant correction factor to the value of I_n to obtain the minimum required tabulated value of I_z (as shown in equation 5), next by using the appropriate table of Appendix 9 of code and having regards to the method of installation identified from table 9A of the appendix and then select the minimum conductor size to satisfy I_z. Lastly is to check that the voltage drop limitation is satisfied and increased the conductor size, if necessary (Paul Cook, 2008; Iman Ziari , 2011; PSERC, 2010).

The current –carrying capacity of a cable is related to the rating of device affording it overcurrent protection, not to the load current. To make ensure that this protection is effective; it is convenient to consider the application of correction factors in the following mathematical to a minimum conductor rating form as shown in equation (5) (Steward W.E. and Beck R.A., 2010).

$$I_z = I_n\left(\frac{1}{Ca} x \frac{1}{Cg} x \frac{1}{Ci}\right) \quad (5)$$

Where; I_z is the effective current-carrying of cable for continuous service; I_n is the nominal current of protective device (or design maximum current for the sub-main); C_a is the ambient temperature factor; C_g is the grouping factor and C_i is the thermal insulation factor

The size of the conductor can be calculated based on equation (5). Table 2 shows the cable size applied to the system as discussed. As an example of calculation, the conductor size for various cases with group factor Cg =0.9 and others factor is 1. So that $\mathrm{I_z}$;

i. Load A, Current for conductor is $\mathrm{I_z} = 200(\frac{1}{1} x \frac{1}{0.9} x \frac{1}{1})$ = 222.22, refer to Figure 3 the suitable XLPE conductor size is 95 mm^2.

FOUR-CORE 600/1000V UNARMOURED CABLES (COPPER CONDUCTOR)

Conductor: Nominal Area	Conductor: Shape	Thickness of Insulation	Thickness of Sheath	Overall Diameter	Approx. Weight	Electrical Characteristics: Current Rating: In Air at 40°C	Current Rating: In Ground at 25°C	Conductor Resistance: dc at 20°C	Conductor Resistance: 50Hz at 90°C
sq. mm		mm	mm	mm	kg/km	amp	amp	Ω/km	Ω/km
16	circular compacted or shaped stranded	0.7	1.8	18.4	820	88	100	1.15	1.47
25		0.9	1.8	26.9	1440	115	135	0.727	0.927
35		0.9	1.8	29.5	1880	140	160	0.524	0.669
50		1.0	1.8	33.3	2470	175	195	0.387	0.494
70		1.1	2.0	38.8	3480	220	235	0.268	0.342
95		1.1	2.1	44.2	4600	265	285	0.193	0.247
120		1.2	2.2	49.5	5900	300	325	0.153	0.196
150		1.4	2.4	55.0	7250	350	365	0.124	0.160
185		1.6	2.6	61.4	9080	410	410	0.0991	0.129
240		1.7	2.8	69.2	11790	480	475	0.0754	0.0996
300		1.8	3.0	76.9	14680	570	535	0.0601	0.0809
400		2.0	3.2	85.2	18440	660	610	0.0470	0.0653

Figure 3: Table of BS-5467 IEC 60502-1

ii. Load B, Current for conductor is $\mathrm{I_z} = 600(\frac{1}{1} x \frac{1}{0.9} x \frac{1}{1})$ = 666.66, as shown in Figure 3 the suitable XLPE conductor size is 2 x 185 mm^2.

iii. Load C, Current for conductor is $\mathrm{I_z} = 200(\frac{1}{1} x \frac{1}{0.9} x \frac{1}{1})$ = 222.22, as shown in Figure 3 the suitable XLPE conductor size is 95 mm^2. But refer to distance and voltage drop the conductor size 120 mm^2 is better to support the length of more than 190 meter.

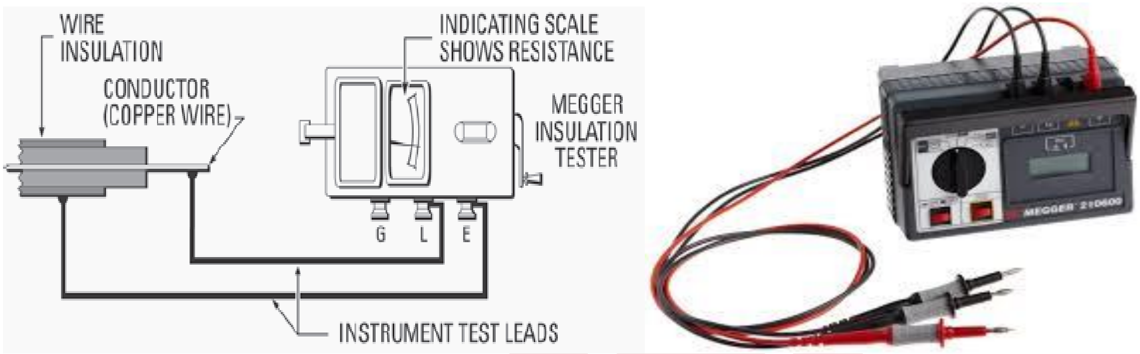
Table 2: Cable Size apply to the System Based on MCB/ACB Rating

Item/ load	MCB/ACB rating (A)	Cable Size
A	200	1 X 95 mm^2 4 Core XLPE/SWA/PVC
B	600	2 X 185 mm^2 4 Core XLPE/SWA/PVC
C	200	1 X 120 mm^2 4 Core XLPE/SWA/PVC
D	50	1 X 150 mm^2 4 Core XLPE/SWA/PVC
E	500	2 X 185 mm^2 4 Core XLPE/SWA/PVC
F	50	1 X 35 mm^2 4 Core PVC/SWA/PVC
G	30	1 X 10 mm^2 4 Core PVC/SWA/PVC
H	100	1 X 70 mm^2 4 Core XLPE/SWA/PVC
I	50	1 X 35 mm^2 4 Core PVC/SWA/PVC
J	50	1 X 50 mm^2 4 Core XLPE/SWA/PVC
K	50	1 X 35 mm^2 4 Core PVC/SWA/PVC
Total	**2 x 1200 (ACB) – 4Pole, 50kA**	**4 X 1200 A TINNED COPPER BASBAR (4 X 60MM X 10 MM)**

3. MSB Testing And Procedure

There are two types of testing on Electrical Main Switchboard; visual and electrical inspection and electrical test (Abb Ltd, 2005; **John Whitfield, 2016**). Visual and electrical inspection will be carried out on the LV switchboard as inspection to the layout of fitted components, check the overall dimension of switchboard, the size of bus bars, cables and earthing conductors and location of feeder entry point; check and verify the brand, model, and circuit identification of devices/components installed such as breakers, current transformers (CT), fuses, ammeters, voltmeters, power meters and protection relays etc.; check overall paint work, door locking device, door gasket, door hinges, door cut-out holes; check the bus bars and cable tightening, the marking, bus bars clearance, base angle bar and plinth; and check the labels, name plate and phase identification. The results of the checking process and customer comments will be recorded in ‘ Testing of LV Switchboard Form’.

The second method of the testing that will be carried out is electrical test, this includes of insulation test and high voltage injection test. The insulate test will be conducted on the carry out 500/1000V meggar test for phase to earth, neutral to earth, phase to neutral and phase to phase to measure the insulation resistance with all breakers in ‘ON’ positions. However the voltage Injection test will be carried out based on the three method tests such as; First, to carry out 500/1000V meggar test between each stressed phase and all other phase connected to exposed conductive parts with all breakers in ‘ON’ positions; Second, to apply 2.5kV AC voltage between each stressed phase and all other phases connected to the exposed conductive parts for 60 seconds and measure the leakage current. Lastly, to repeat the first test as mentioned before (Edvard, 2012).. Figure 4 and 5 show the diagram of Insulation test and current injection test respectively.



(a) **(b)**

Figure 4: (a) Insulation Test and (b) Megger Insulation Tester

Figure 4(a) describes the generator can be hand-cranked or line-operated to develop a high DC voltage which cause a small current through and over surfaces of the insulation being tested (conductor and wire insulator). This current (usually at an applied voltage of 500/1000 volts or more) is measured by the ohmmeter, which has an indicating scale. Detailed specification can be found in Electrical Engineering Portal (Edvard, 2012). Figure 4(b) shows the new model Megger Insulation Tester being used now day.

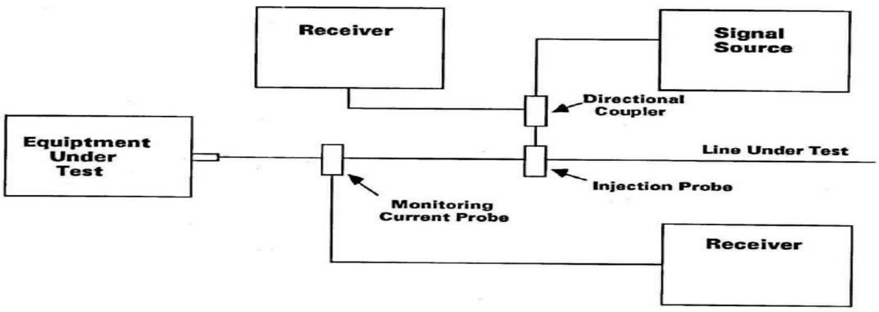


Figure 5: Current Injection Test

Figure 5 shows the test method of current injection test. The test procedure to be followed as stated; Remove all external connections before doing the test. Then connect the remaining phases and to earth. Confirm that no other person is in contact with the bus. Next , apply the AC voltage by using hi-pot kit (2.5 kV/60 sec). Then, note down the leakage current. Lastly discharge the charge after the test (A.H. Systems,2005).

4. Result and Discussion

4.1. Devices/Components Installed in Main Switchboard

Figure 6 shows the devices installed in MSB. It shows many MCCBs installed in separate compartments for overload protection.

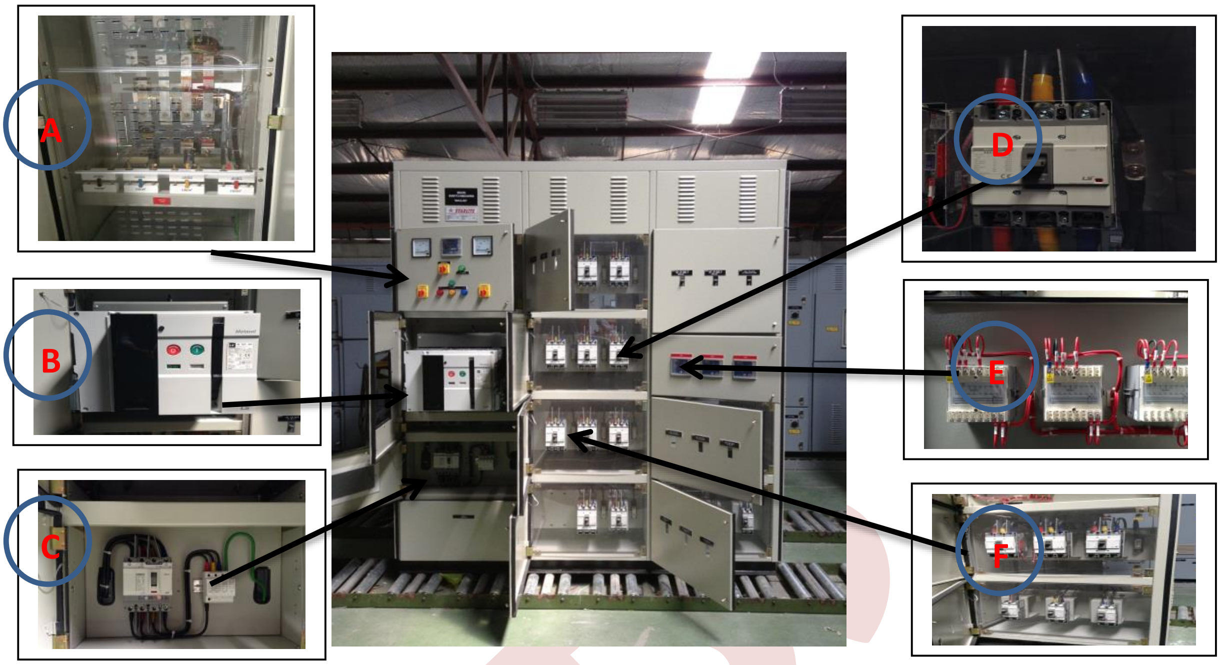


Figure 6: Devices installed in MSB

Table 3 shows devices installed in the MSB panel as labeled in Figure 7.

Table 3: Devices Install in MSB Panel

Label	Items/Devices
A	Incoming TNB Supply (back panel)
B	Air Circuit Breaker (ACB)
C	Surge Protection
D	Molded Case Circuit Breaker (MCCB)
E	Earth Leakage relay (ELR) Devices
F	Molded Case Circuit Breaker (MCCB)

4.2. Visual and Electrical Inspection Test

Figure 7, 8, and 9 are shows the pictures of visual and electrical tests which were conducted during the testing. Inspections are based on the standards approved by Jabatan Kerja Raya Malaysia (JKR), Tenaga Nasional Berhad (TNB), or any local authority agencies as well as tender document.

Figure 7 : Iinspections of fitted components check and verify the brand, model, and identification components installed (breakers, current transformers (CT), fuses, ammeters, voltmeters, power meters and protection relays etc.)

Figure 8 : Inspections of overall dimension of switchboard, check overall paint work, door locking device, door gasket, door hinges, door cut-out holes

Figure 9 : Inspections location of feeder entry point, cables and earthing conductors, cable tightening, and bus bars clearance

Table 4 and 5 showed the results recorded for visual and electrical inspection tests. All the entire tests were passed.

Table 4: Results of Visual and Electrical Inspection Test of MSB Panel

No.	Visual Check	Result
1.	Dimensional arranged by layout (width, heigh, depth)	PASSED
2.	Metal parts are assembly properly	PASSED
3.	Colour specification	PASSED
4.	Clean up/vaccum	PASSED
5.	Components: • Metering arranged by drawing layout (brand/model/made etc.) • Protection relay (brand/model/made etc.) • ACB/MCCB/MCB (brand/model/made/rating etc.) • Current Transformer (CT) (brand/model/made/rating etc.) • Capasitor Bank (brand/model/made/rating etc.)	PASSED PASSED PASSED PASSED PASSED

Table 5: Results of Electrical Electrical Inspection Test of MSB Panel

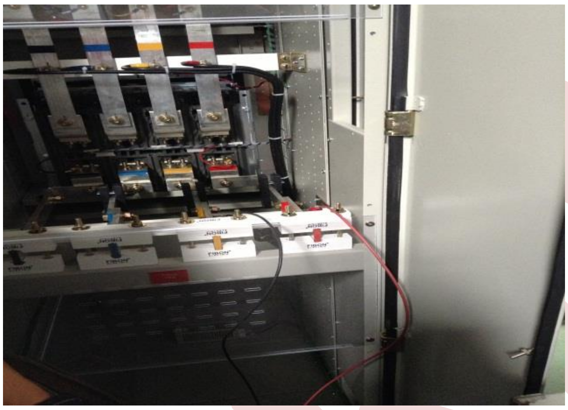
No.	Electrical Check	Result
1.	Routing is arranged by drawing layout (bas bar/cable)	PASSED
2.	Busbar (rating/incoming/outgoing etc.)	PASSED
3.	Busbar c/w phase colour indication (RYBNE)	PASSED
4.	Sufficient distance (min 20mm) – Phase to phase and basbar to any metal	PASSED
5.	Other; • Bolts & nuts for incoming and outgoing cable • Tightness – bolt and nuts/washer/spring • Cable sizing • Cable c/w phase colour indication (RYBN) • Proper cabling • Mechanical Protection From Live Conductor • All live conductor protection)	PASSED PASSED PASSED PASSED PASSED PASSED

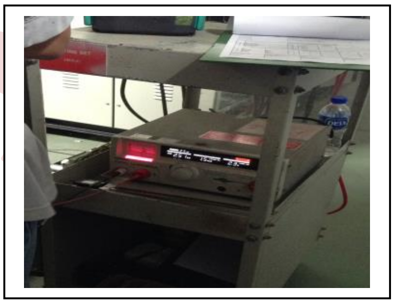
	• Earthing (sufficient earth bar sizing & length) • Earth wire is connected firmly between door and body • Labeling (Correct description by drawing layout)	PASSED PASSED PASSED

From the results it shown that the design and installation devices of MSB are complied with the standards or criteria imposed by Jabatan Kerja Raya (JKR), Tenaga Nasional Berhad, tender document as well as IEE installation regulation. As a result, these indicated and implied that the MSB are safe and secure.

4.3 Electrical Test

Electrical tests were conducted with insulation test as procedure discussed before and followed by the current injection test. Figure 10 shows the current injection Test conducted on the MSB panel at Competent Manufacturer. The results are recorded in Table 6 and 7 respectively.





(a) Test Point on MSB Panel **(b) Voltage-Tester**

Figure 10: Current Injection Test Conducted At Competent Switchboard manufacturer.

Table 6: Busbar/Insulation Test

No.	Test Connection	Nos. Outgoing Feeder	1000 V Insulation/Continuity Test (Min 20Mohm)	Retest of Insulation After Pressure (min 20Mohm)
1	Red/Earth	17	384	343
2	Yellow/Earth	17	449	400
3	Blue/Earth	17	428	397
4	Neutral/Earth	17	229	217
5	Red/Neutral	17	322	299
6	Yellow/Neutral	17	341	317
7	Blue/Neutral	17	297	285
8	Red/Yellow	17	365	352
9	Yellow/Blue	17	340	331
10	Blue/Red	17	378	366

Table 6 shows that the test for insulation test is passed. This is because all the test connection between phases and earth measured for continuity test before and after the pressure is applied within the range (not less than 20 Mohm).

Table 7: current injection test (60 Sec)

Test Connection			**Impulse AC Voltage Withstand**	
No.	**Stressed Phase**	**Between Phase**	**Leakage (max 30 mA)**	**remark**
1	Red/Earth	Yellow	2.7	Passed
2	Yellow/Earth	Blue	2.3	Passed
3	Blue/Earth	Blue	2.4	Passed
4	Neutral/Earth	Red	2.2	Passed
5	Red/Neutral	Yellow	2.2	Passed
6	Yellow/Neutral	Blue	2.8	Passed
7	Blue/Neutral	Red	1.6	Passed
8	Red/Yellow	Yellow	1.5	Passed
9	Yellow/Blue	Blue	1.7	Passed
10	Blue/Red	Neutral	2.6	Passed

Table 7 shows that for injection test with 2.5KV within 60 seconds between phases measured for leakage current are between 1.5 mA to 2.8 mA. This implied that all values passed is due within the allowed range (max 30mA).

5. Conclusion

The successfully application of MSB depended on the designing and installation of devices or component of MSB. This paper had discussed both the criteria as well as testing process. The testing process is conducted at a third party company which comply to the standards imposed by Tenaga Nasional Malaysia (Ehsan), Jabatan Kerja Raya Malaysia as well as the standards adopted by the Institute of Electrical and Electronic (IEE) Installation Regulation. From the results as discussed in 4.2 and 4.3 for visual and electrical inspection test and electrical test respectively had shown that all the tests are passed and complied with the standards imposed to the test and installation of MSB. As a result, these indicated that the MSB product is safe and secure as well as complies to be installed in related buildings and is guaranteed to be safe from tripping, burning and even fatal error to the equipment or people.

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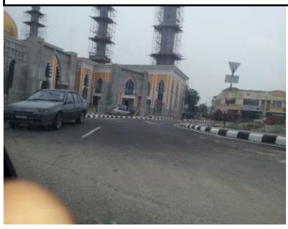
The Al-Ismaili mosque (Masjid Al-Ismaili) was inaugurated in 2014 based on a concept by Sultan Muhammad V, dedicated to his father, the Sultan Ismail Petra. The mosque is located at Wakaf Bharu, a suburb of Kota Bharu. Construction began in 2011 and was completed in 2014. Following the five pillars of Islam the mosque has five minarets, five staircases and six domes symbolising the six pillars of faith. The main prayer hall has an area of 1880 m² and can accommodate 1500 people.
http://www.molon.de/galleries/Malaysia/EastCoast/KBharu/img.php?pic=24

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