Analysis of Transformer Loading Profile at 11/0.4 kV Distribution Voltage Network at Hospital Melaka

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Abstract – O*n distribution site, to offer customers with comfort in service, the dependability, stability, and residual lifetime of the transformer is important part to consider. The factors that affect the lifetime duration of a transformer are the ambient temperature, transformer oil temperature, and pattern of the consumed load. This paper discusses the load current demand profile of the transformers in three substations, Substation 1-3 (SS1-SS3) at Hospital Melaka. The load current demand profile is measured and recorded using Power Logger Fluke 175. The data logger is installed at main switch board feeder 1 and feeder 2 between 10 to 15 days. The normal loading and short time overloading (due to the contingency when the power supply is breakdown) of the transformers are analyzed in this paper. The finding shows that in normal loading conditions, each substation's transformer is loaded between 30% and 60% of its capacity, and its lifespan is anticipated to be more than ten years. Meanwhile, the short-time overloading of step-up distribution transformer at SS2 (TG1 and TG2) can be improved by raising the transformer size to 1600 kVA and 2000 kVA. This could prevent the transformer loading swing over its full capacity in accordance with the IEC 60076-7 guidelines.*

Keywords: *current profile, full load current, maximum current demand, transformer loading*

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I. Introduction

In general, transformer is one of the important equipment in the operation of electrical power system for distributing electrical power from high voltage to low voltage or vice versa. To satisfy its technical life expectations and to guarantee that consumers have uninterrupted electricity, the transformer must be properly maintained. Unfortunately, transformers on the other hand, are frequently overlooked and neglected electrical equipment [1]. Because of that, the previous researchers have been examining the factors impacting transformer dependability to avoid transformers from performing poorly and exceeding their expected lifetime. The ambient temperature, transformer's oil and load pattern is three elements that influence the transformer's lifetime or ageing. When the load is at 100%, the transformer's average life is the shortest. The ageing rate of the transformer increases as the load factor and ambient temperature rise resulting in a reduction in the transformer's life [2].

The analysis of the effect of loading on the oil natural air natural (ONAN) transformers usage time is described in [3]. If the transformer is loaded to 100%, the age difference will be 2.52 p.u/day, giving a remaining life of 10 years. With a load of 90%, the transformer will experience an age difference of 1.44 p.u./day, giving it another 18 years of service life. The transformer will then experience an age difference of 0.67 p.u/day for an 80% load, giving it a remaining life of 38 years to carry out the operation again.

The study of transformer lifetime due to the loading process on distribution line is described in [4]. The distribution transformer with varied loads, 50%-60 %, 70%-80%, and 80%-90%, is evaluated, and the transformer loading above 80% has the lowest residual lifespan when compared to others.

In [5], the power transformer loading analysis to improve the reliability of a substation is presented. According to the study's findings, the peak load of power transformers in the period from 2014 to 2016 is still at a safe level, with the highest peak load equals to 93% of the transformer's overall capacity. However, it is advised to include the prediction of the demand growth in the transformers in the period from 2014 to 2016 is still at a safe level, with the highest peak load equals to 93% of the transformer's overall capacity. However, it is advised to include the prediction of the demand growth in the following years when determining the capacity of power transformer. Therefore, while choosing a transformer device, the load status of the transformer should be considered.

The load conditions of distribution transformers can be classified into four types [6], [7], which are normal life expectancy loading, planned overloading, long time overloading and short time overloading. When the transformer is used under continuous conditions, the typical life expectancy can be expected. The distribution transformer will be overloaded during the precise period that is usually in utility operation in the planned overloading condition. The precise moment at which the tolerable loss of life can be attained is determined. If the transformer is powered over its nameplate rating for an extended period due to a power loss or transmission system issues, the transformer is in the long-term overloading situation. Meanwhile, if the transformer is heavily loaded for a short period when the system's power source fails, the category loading transformer is in an overloading state. To avoid failure, either this type of loading should be reduced, or the transformer should be unplugged within that time frame, as specified by the IEC 60076-7 standard [8].

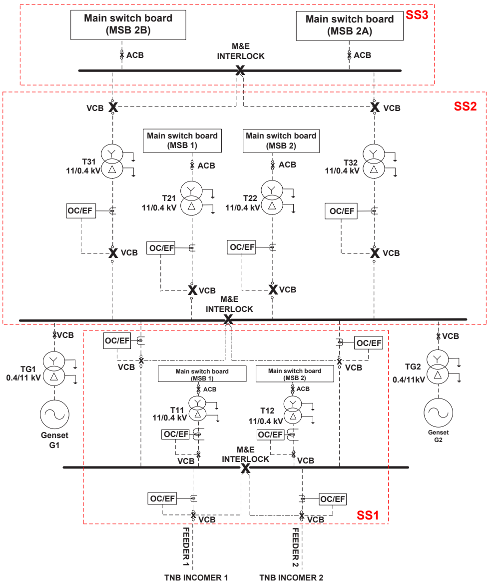
According to previous work of operational transformer, analyzing the current load pattern profile is an important consideration during the designing stage of the electricity demand. This is due to the significant performance of transformer for residential building. In this paper, the analysis of current pattern profiles is presented. The calculation of transformer loading based on maximum current demand at each substation in Hospital Melaka is described. Section II presents the distribution of medium voltage single line diagram and the location of power logger to measure the current profiles. The current profile and transformer loading are presented in section III. The existing for each substation and preferable size of distribution set-up power transformer for Substation 2 is summarized in Section IV.

II. Power Distribution of Medium Voltage (MV)

Fig. 1 shows the medium voltage (MV) distribution for Hospital Melaka. The distribution network consists of three substations numbered from 1 to 3. In accordance with IEC 62271-200 for metal enclosed switchgear, all the three substations are installed with mechanical and electrical interlocking (M&E interlock) devices.

Substation 1 (SS1) receives 11 kV from TNB Taman Cempaka station and distributes to feeder 1 and 2. Two units of 1000 kVA step-down distribution transformers (11/0.4 kV), T11 and T12, are installed between the two feeders and the load user in substation 1, respectively. Feeder 1 and 2 feeds the MV distribution at substation 2 (SS2) where two step-down 1500 kVA distribution transformers (11/0.4 kV), T21 and T22, are placed between the incoming feeder 1 and feeder 2, and the load user, respectively. Substation 2 feeds Substation 3 (SS3) that are equipped with two step-down 1500 kVA distribution transformers (11/0.4 kV), T31 and T32.

The two combinations of a genset and a step-up transformer (0.4/11 kV) make this distribution system appealing. This is for backup and to ensure that the utility is always provided with power to load if the incoming TNB line fails.



OC/EF: Overcurrent/Earth Fault
VCB: Vacuum Circuit Breaker
ACB: Air Circuit Breaker

Fig. 1. Distribution of Medium Voltage Network

A. *Distribution Transformer at Normal Loading*

Distribution transformers are generally used in electrical power distribution with smaller voltage range compared to power transformer [9]. In designing an optimal distribution of medium voltage system, the distribution transformer is the main factor to consider. The selection of power distribution transformer is determined by estimating the ampere demand and ampere rating of transformer. For a distribution transformer, increasing the size of the primary and secondary windings will increase the ampere rating while increasing the voltage rating of the insulation used in the transformer will increase the voltage rating of the transformer [10].

In designing an optimal distribution transformer, the full load and demand current should be defined. The existing system uses the oil forced air forced (OFAF) type distribution transformer 1000 kVA and 1500 kVA rating.

The full load current at low voltage (LV) or medium voltage (MV) distribution side for each substation is estimated as in (1). According to [11], at voltage level less than 132 kV, the required minimum power factor (PF) is 0.85 to maintain their load performance.

$$I_{Full\ load} = \frac{Real\ Power\ (Watt)}{\sqrt{3}VI\ PF} \qquad (1)$$

Furthermore, the transformer loading at each point TL_{P_n} can be estimated using the values of full load current I_{FL} and demand current I_{MD} as in (2).

$$(\%TL_{nm}) = \frac{I_{Demand\ Load}}{I_{Full\ Load}} x100\% \qquad (2)$$

where n =1/2/3/G1/G2 (SS1/SS2/SS3/Genset 1/Genset 2) and m = 1/2 (feeder 1 / feeder 2)

B. Distribution Transformer at Short Time Over Loading

The backup generator is advised to be considered while developing the distribution electrical system in the premise building. The two-unit generators (G1 & G2) with step-up transformer (TG1 and TG2) are incorporated to the Hospital Melaka's existing distribution power infrastructure. If the power supply from TNB fails, G1TG1 and G2TG2 serve as backup power distribution. To prevent the contingency cases such as due to heavy load, short circuit faults, generator tripping or load shedding as summarized in Table I, the transformer load swing (TLS) of TG1 or TG2 at feeder 1 or feeder 2 should be considered. The %TLS expression of TG1 or TG2 is defined in (3). TLS is advised to be less than 80% to extend the life of the transformer and prevent overloading.

TABLE I
TRANSFORMER LOAD SWING IF SHORT TIME OVERLOADING CONDITION

Generator at feeder 1	Generator at feeder 2	Transformer load swing at feeder 1/feeder 2 (TG1 or TG2)
Breakdown	No breakdown	TG2 will TLS
No breakdown	Breakdown	TG1will TLS

$$(\%TLS_{TG1\ or\ TG2}) = \%TLS_{TG1} + \%TLS_{TG2} \qquad (3)$$

C. Current Profile Measurement Point at SS1 to SS3

The profile of each phase current is measured using Power Analyzer Fluke 1750. The measurement points are indicated with points P1, P2, P3, P4, P5 and P6 for each substation at low voltage site. Fig. 2 to Fig.4 show the measurement point location of substation 1 (SS1), 2 (SS2) and 3 (SS3), respectively. The voltage and current at P1 to P6 are measured between 10 to 15 days as summarized in Table II.

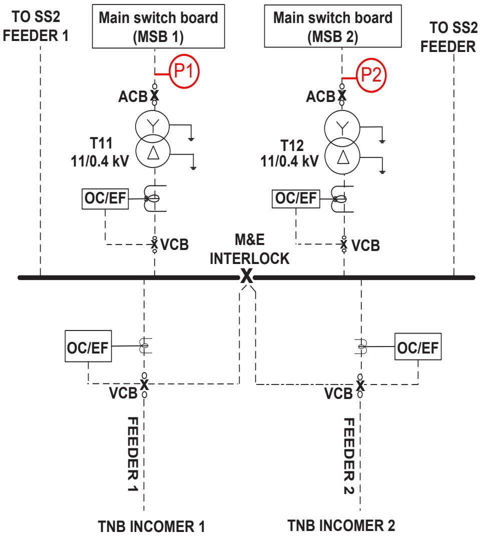


Fig. 2. Measurement points for SS1 location

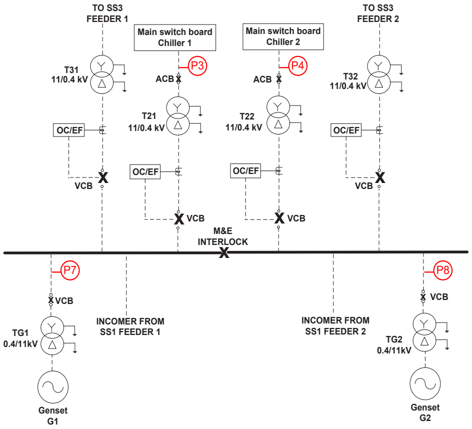


Fig. 3. Measurement points for SS2 location

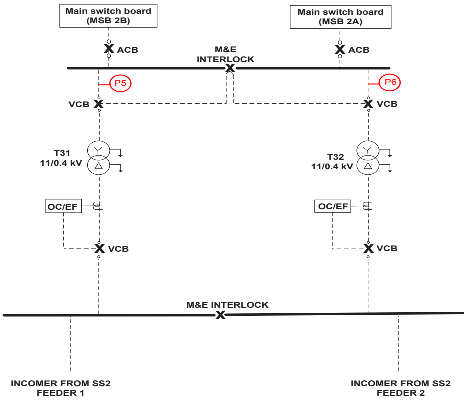


Fig. 4. Measurement points for SS3 location

TABLE II
LOCATION AND TIME DATA LOGGER

Location	Point Measurement	Start Time	End Time	Duration
SS1	P1	26/10/2021 (Tuesday) 12:18:01pm	10/11/2021 (Wednesday) 12:12:49 pm	14 (days) 23 (hours) 54 (minutes) 48 (seconds)
	P2	26/10/2021 (Tuesday) 11:44:04 pm	10/11/2021 (Wednesday) 12:28:17 pm	15 (days) 00 (hours) 44 (minutes) 13 (seconds)
SS2	P3	15/10/2021 (Friday) 11:28:31am	26/10/2021 (Tuesday) 10:17:35am	10 (days) 22 (hours) 49 (minutes) 04 (seconds)
	P4	15/10/2021 (Friday) 11:01:52 am	26/10/2021 (Tuesday) 10:02:07am	10 (days) 23 (hours) 00 (minutes) 15 (seconds)
SS3	P5	04/10/2021 (Monday) 4:56:18 pm	15/10/2021 (Friday) 09:31:11 am	10 (days) 16 (hours) 34 (minutes) 53 (seconds)
	P6	04/10/2021 (Monday) 4:40:56 pm	15/10/2021 (Friday) 09:44:22 am	10 (days) 17 (hours) 03 (minutes) 26 (seconds)

III. Power Logger Data Recording

The Power Analyzer Fluke 1750 automatically records the power quality parameter and event, on every cycle. During the monitoring period, the detailed current profile of low voltage side in terms of maximum and minimum current demand is recorded. The average rms current demand at phases 1 (RMS Avg L1), phase 2 (RMS Avg L2) and phase 3 (RMS Avg L3) at each voltage substation (SS1, SS2 and SS3) are tabulated in Table III to Table VIII. The maximum average current demand at measured point (P1 to P6) in SS1 to SS3 as tabulated in Table IX, are 896.26 A_{rms}, 804.87 A_{rms}, 663.60 A_{rms}, 1187.7 A_{rms}, 602.66 A_{rms}, and 919.65 A_{rms} respectively. The highest current demand measured at P7 and P8 for the medium voltage site is 21.91 A_{rms} and 33.43 A_{rms}, respectively.

TABLE III
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P1 SS1

Phase	Max (A_{rms})	Date/Time	Min (A_{rms})	Time
RMS Avg L1	769.77	9/11/2021 12:10:00	188.22	2/11/2021 05:00.00
RMS Avg L2	896.26	9/11/2021 11:10:00	231.77	5/11/2021 04:30:00
RMS Avg L3	819.86	9/11/2021 15:00:00	207.33	6/11/2021 00:20:00

TABLE IV
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P2 SS1

Phase	Max (A_{rms})	Date / Time	Min (A_{rms})	Time
RMS Avg L1	757.54	27/10/2021 16:00:00	334.97	10/11/2021 03:00.00
RMS Avg L2	804.87	27/10/2021 16:00:00	309.46	10/11/2021 03:00:00
RMS Avg L3	751.32	29/10/2021 12:30:00	265.03	10/11/2021 03:00:00

TABLE V
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P3 SS2

Phase	Max (A_{rms})	Date / Time	Min (A_{rms})	Time
RMS Avg L1	663.60	15/10/2021 11:40:00	96.73	17/10/2021 18:20.00
RMS Avg L2	634.04	15/10/2021 11:28:31	79.01	22/10/2021 19:00:00
RMS Avg L3	637.14	25/10/2021 15:40:00	79.10	17/10/2021 17:40:00

TABLE VI
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P4 SS2

Phase	Max (A_{rms})	Date / Time	Min (A_{rms})	Time
RMS Avg L1	1187.79	16/10/2021 09:30:00	424.76	21/10/2021 06:10.00
RMS Avg L2	1180.77	16/10/2021 09:30:00	431.68	21/10/2021 06:10:00
RMS Avg L3	1180.99	16/10/2021 11:50:00	399.30	21/10/2021 06:10:00

TABLE VII
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P5 SS3

Phase	Max (A_{rms})	Date / Time	Min (A_{rms})	Time
RMS Avg L1	602.66	14/10/2021 12:00:00	257.27	05/10/2021 03:50.00
RMS Avg L2	522.05	12/10/2021 10:00:00	208.75	09/10/2021 05:40:00
RMS Avg L3	532.36	14/10/2021 11:50:00	229.17	05/10/2021 03:10:00

TABLE VIII
MAXIMUM AND MINIMUM OF CURRENT DEMAND AT P6 SS3

Phase	Max (A_{RMS})	Date / Time	Min (A_{rms})	Time
RMS Avg L1	602.66	14/10/2021 12:00:00	257.27	05/10/2021 03:50.00
RMS Avg L2	522.05	12/10/2021 10:00:00	208.75	09/10/2021 05:40:00
RMS Avg L3	532.36	14/10/2021 11:50:00	229.17	05/10/2021 03:10:00

TABLE IX
SUMMARIZED OF MAXIMUM CURRENT DEMAND AT LOW VOLTAGE SIDE AND MEDIUM VOLTAGE SIDE

Location	Measured Point	Max (A_{rms})
SS1 (LV)	P1	896.26
	P2	804.87
SS2 (LV)	P3	663.60
	P4	1187.79
SS3 (LV)	P5	602.66
	P6	919.65
SS4 (MV)	P7	21.91
	P8	33.43

IV. Load Conditions of Transformers at Substation SS1 to SS3

From the logging data of maximum current demand at low voltage side (LV) and medium voltage side (MV) as tabulated in Table IX, the estimation of transformer loading (using equation 2) at point P1to P8 for the three substations are summarized in Table X. Table X indicates that the step-down transformer loading at SS1 to SS3 is 62%, 56%, 31%, 55%, 28%, and 42%, respectively, at transformers TL_{T11}, TL_{T12}, TL_{T21}, TL_{T21}, TL_{T22}, TL_{T31} and TL_{T32}. The transformer loading for the step-up transformers at TL_{G1} and TL_{G2} are 42% and 64%, respectively, causing a transformer load swing issue as described in Section II-B. For example, if the contingency occurs at P7, the transformer at P8 will operate to supply the feeder 1 and feeder 2 with a transformer load swing of 106% (overloading condition as stated in IEC 60076-7). Overloading issue could harm the insulation of the transformers and resulting in transformer failure.

Because of the overloading issue, it is advised that the power capacity of the transformer be increased. Taking the availability market of distribution transformer into consideration, the recommended power rating of 1600kVA and 2000kVA are considered and the tabulated in Table XI and XII. According to Tables XI and XII, the percentage of transformer loading swing (TLS) for the backup or contingency scenario at points P7 and P8 will prevent the overloaded issue. With the 1600kVA and 2000kVA capacity, the transformer loading at TL_{TG1} or TL_{TG2} are 66% (26% + 40%) and 53% (32% + 21%) respectively and can be operated without failure or overloading condition.

TABLE X
EXISTING TRANSFORMER LOADING AT TL_{T11} – TL_{TG2}

Transformer Rating	Sub station	I_{LVFL} & I_{LVMD} I_{MVFL} & I_{MVMD}		Transformer Loading (TL)	
		P1	**P2**	**TL_{T11}**	**TL_{T12}**
11/0.4 kV 1000 kVA Step-down OFAF	SS1	I_{LVMD} 896.26 A I_{LVFL} 1443.4 A	I_{LVMD} 804.87A I_{LVFL} 1443.4 A	62%	56%
		P3	**P4**	**TL_{T21}**	**TL_{T22}**
11/0.4 kV 1500 kVA Step-down OFAF	SS2	I_{LVMD} 663.60 A I_{LVFL} 2165.1 A	I_{LVMD} 1187.79A I_{LVFL} 2165.1 A	31%	55%
		P5	**P6**	**TL_{T31}**	**TL_{T32}**
11/0.4 kV 1500kVA Step-down OFAF	SS3	I_{LVMD} 602.66 A I_{LVFL} 2165.1 A	I_{LVMD} 919.65 A I_{LVFL} 2165.1 A	28%	42%
		P7	**P8**	**TL_{TG1}**	**TL_{TG2}**
0.4/11 kV 1000kVA Step-up OFAF	SS4	I_{MVMD} 21.91 A I_{MVFL} 52.5 A	I_{MVMD} 33.43 A I_{MVFL} 52.5 A	42%	64%

TABLE XI
RECOMMENDED TRANSFORMER LOADING (TG1 & TG2) BY INCREASING THE TRANSFORMER RATING (1600 kVA) AT POINT P7 & P8

Transformer Rating	Sub station	I_{LVFL} & I_{LVMD} I_{MVFL} & I_{MVMD}		Transformer Loading (TL)	
		P7	**P8**	**P7**	**P8**
0.4/11 kV 1600 kVA Step-up OFAF	SS2	I_{MVMD} 21.91 A I_{MVFL} 84 A	I_{MVMD} 33.43 A I_{MVFL} 84 A	26%	40%

TABLE XII
RECOMMENDED TRANSFORMER LOADING (TG1 & TG2) BY INCREASING THE TRANSFORMER RATING (2000 kVA) AT POINT P7 & P8

Transformer Rating	Sub station	I_{LVFL} & I_{LVMD} I_{MVFL} & I_{MVMD}		Transformer Loading (TL)	
		P7	**P8**	**P7**	**P8**
0.4/11 kV 2000 kVA Step-up OFAF	SS2	I_{MVMD} 21.91 A I_{MVFL} 84 A	I_{MVMD} 33.43 A I_{MVFL} 84 A	21%	32%

Fig. 5 displays the 1000kVA, 1600kVA and 2000kVA transformer ratings in relation to the percentage of transformer loading. When the rating is raised to 1600kVA or 2000kVA, the step-up transformer loading at TG1 and TG2 decreases. Transformer loading at TG1 and TG2 with 1600kVA capacity is reduced by 16% and 24%, respectively, compared to 42% and 64% of transformer loading with an existing capacity of 1000kVA. When the transformer rating is increased to 2000kVA, the transformer loading decreases by 5% and 8%, respectively, compared to the 1600kVA transformer rating.

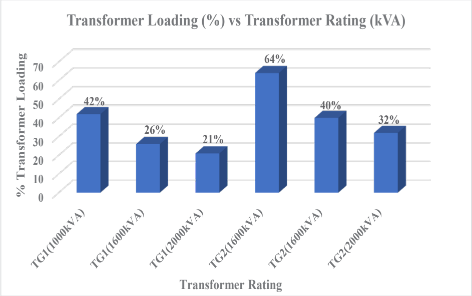


Fig. 5. Transformer rating vs percentage of transformer loading

V. Conclusion

This study presents an analysis of transformer loading at low and medium voltage for distribution voltage in Hospital Melaka. The load current profile is measured within 10 to 15 days. The obtained results demonstrate that the most load current is consumed on weekdays. The results show that a substantial amount of both transformer loading at T11 and T12 of Substation 1 (more than 50%) is consumed during the daytime. Due to the possibility of transformer overloading in the event of an emergency, the transformer rating at TG1 and TG2 should be increased to 1600 kVA or 2000 kVA.

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