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A Study Of Adjusting Distribution Transformer Capacity To Consumer Loads At PT PLN (Persero) ULP Medan Johor

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ABSTRACT

The distribution transformer is a very vital component for medium voltage distribution systems. However, it is not uncommon for distribution transformers to experience interference. One of them is transformer overload. The cause of the overload is the load attached to the transformer which becomes hot and results in an increase in the winding temperature in the transformer coil. The increase in winding temperature can cause damage to the winding insulation on the transformer coil which is at risk of damage to the transformer and can result in the interruption of electricity distribution to consumers. According to references, ideally a transformer is loaded at 80% of the maximum capacity of the transformer. But the reality in the field is that there are still many distribution transformers that are loaded beyond their maximum capacity. One effort that can be done to deal with this is to increase the power capacity (uprating). After the distribution transformer uprating activity, it can be seen that the percentage of load served by the distribution transformer which was previously overloaded can be reduced.

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INTRODUCTION

Electrical energy is one aspect that cannot be separated from human life. Along with population growth and development in this countrythen the need for electricity will also increase. Thus, PT .. PLN (Persero) as an electricity provider must have good planning regarding the distribution of electricity to consumers. Distribution transformers as important components in the distribution of electricity must also be considered and maintained so that they can operate optimally. The selection of ratings for distribution transformers that are in accordance with load requirements is very important because it can affect the life of the distribution transformer. According to the standard reference set by SPLN Number 50 of 1997, the permitted load is a maximum of 80% of the written capacity. If a distribution transformer is overloaded and left continuously, it can cause the distribution transformer to become contact and damaged. One of the efforts made by PLN as the party responsible for handling this is to uprate the transformer. By uprating this transformer, it is hoped that the supply of electricity to consumers can be better maintained.

Distribution transformers play an important role in the electric power system because they function to reduce the voltage from the primary distribution network to a voltage level that can be used by consumers. PT PLN (Persero) Medan Johor Customer Service Unit (ULP) as part of the electricity distribution system is responsible for maintaining the reliability and quality of electricity supply to customers.

As the number of customers grows and electricity consumption increases, the load on distribution transformers also changes. Loads that exceed the transformer capacity can cause electrical disturbances such as low voltage, power outages, and reduced operating efficiency. Therefore, studies are needed to adjust the capacity of distribution transformers to suit customer load requirements in order to improve service quality and distribution system efficiency.

Literature Review

Distributin System

Distribution System plays an important role in the electric power system. This is because this system is directly connected to the electricity users of customers in medium voltage and low voltage channels. The Distribution System itself has functions including receiving electricity from the power source, also distributing the power to consumers. Distribution Substation is one of the components of an electric power distribution system. In this distribution substation, a Distribution Transformer is usually used which functions to reduce the electric voltage from the high voltage distribution network to the voltage used in the low voltage distribution network (step down transformer); for example, a voltage of 20 KV to a voltage of 380 volts or 220 volts. The transformer will work continuously if the transformer is at its nominal load. However, if the load served approaches 100% or even greater than 100%, the transformer will get more heat and can shorten the life of its insulation. Transformers have limitations in their operation. If the transformer is used continuously in overload conditions, it will experience an increase in temperature and heat in the transformer will increase, so that it will damage the insulation, materials and transformers will be damaged. In addition, it affects the quality of transformer power, voltage drop at the end of the network and results in reduced life of the transformer. A transformer is said to be overloaded if its load capacity is more than 80% (SPLN 50: 1997). If this happens for a long time, the insulation on the transformer is damaged due to excessive heat which leads to damage to the transformer. In addition, overload on distribution transformers can also cause voltage drop. There are two alternative methods to overcome transformer overload problems, namely by installing insert transformers and uprating transformers. The Uprating method is one method to overcome overload. This method aims to increase the power capacity of transformers that experience Overload or overload disturbances. The uprating method is by adding transformer power.

Understanding Transformers

Transformer is an electrical device that can transfer and change electrical energy from one or more electrical circuits to another electrical circuit "Primary winding to secondary winding" across a magnetic coupling. Transformers are widely used, both in the fields of electricity and electronics. Its use in the electric power system allows the selection of appropriate and economical voltage for each need, for example, the need for high voltage in the transmission of electric power over long distances.

Distribution transformers are devices that play an important role in distribution systems. Distribution transformers convert medium voltage to low voltage. Distribution transformers that are commonly used are 20 kV/380 V step-down transformers. The phase-to-phase voltage of the low-voltage network system is 380 V. Because there is a voltage drop, the low-voltage rack is made above 380 V so that the voltage at the receiving end is not less than 380 V. Current will flow in the primary coil if the primary coil is connected to an alternating voltage source, so that a number of magnetic lines of force (flux = ▯) will be formed in the transformer core made of ferromagnetic material. Because the current that flows is alternating current, the flux formed in the core will have a changing direction and amount. If the current that flows is sinusoidal, then the flux that occurs will also be sinusoidal. Because the flux flows through the core where there are primary and secondary windings, then in the primary and secondary windings there will be an induced emf (electromotive force), but the direction of the primary induced emf is opposite to the direction of the secondary induced emf. While the frequency of each voltage is the same as the frequency of the source. The installed distribution transformer power usually varies, including: 16 kVA, 25 kVA, 50 kVA, 100 kVA, 160 kVA, 200 kVA, 315 kVA, up to 400 kVA. In the use of distribution transformers, transformer loading is an important point to note because the life of the transformer will be shorter if the transformer is loaded above its capacity, therefore it is important to carry out maintenance actions so that the transformer can work in normal conditions.

Causes of Transformer Failure

The causes of transformer failure are as follows:

a. Overload and unbalanced load

This unbalanced load occurs because the load installed right on the transformer exceeds the maximum capacity loaded to the transformer where the output current exceeds the load current on the transformer. If excessive heat occurs, the wire will no longer be able to withstand the load, this is what is known as overload.

b. Overvoltage due to lightning

This disturbance occurs because of a lightning strike that hits the phase wire, which causes a traveling wave and propagates through the phase wire and then causes interference to the transformer. If the arrester is not functioning, then it is very likely to happen. Under normal conditions, the arrester flows the overvoltage current from the lightning strike to the ground. However, if there is damage to the arrester, the lightning current will not be flowed to the ground by the arrester so that it flows to the transformer. Leaking insulator or broken bushing.

In an electric power distribution system, overload disturbance is defined as the service load to electricity customers that exceeds the capacity of the existing electric power system, for example a distribution transformer with a capacity of 100 kVA, but serves customers greater than its capacity (100 kVA). This causes the transformer to work in abnormal conditions. This condition may not cause spontaneous damage, but if it continues it will shorten the life time of the transformer or accelerate the aging process and cause damage. A transformer is said to be overloaded if its load capacity is more than 80% (SPLN 50: 1997). If this happens continuously for a long period of time, the insulation on the transformer will be damaged due to excessive heat which will result in damage to the transformer. In addition to JTR management, there are 2 alternative methods to overcome the overload problem, namely by inserting a transformer and uprating the transformer.

METHOD

Research location: PT PLN (Persero) Medan Johor Customer Service Unit or hereinafter referred to as ULP Medan Johor is one of the ULP (Rayon) under the auspices of UP3 (Area) Medan. ULP Medan Johor is located at Jl. To meet the electricity needs of the Medan Johor distribution network, there are 8 feeders at PT PLN (Persero) ULP Medan Johor, namely NR 03, NR 04, NR 08, NR 09, TI 07, TI 08, TK 04, TT 02. These feeders are supplied from 2 main substations, namely the Namorambe main substation and the Titi Kuning main substation.

Things that must be done before carrying out distribution transformer uprating activities are to check the power capacity and load on all distribution transformers located in the PT PLN (Persero) ULP Medan Johor area. To find out which transformers can be considered overloaded according to the standards set at PT PLN (Persero) ULP Medan Johor and according to the standard reference set by SPLN Number 50 of 1997, namely the permitted load is a maximum of 80% of the maximum capacity of the transformer because it is considered to have the potential to reduce the life of the transformer from its original age and even cause permanent damage to the transformer. The creation of this route is based on the results of measuring the percentage of load on the transformer and also reviewing the exact location of the distribution substation to be uprated. Furthermore, the implementation of transformer uprating is to be tested with the aim of reducing the number of distribution transformers that are overloaded. To find out the list of distribution transformers that are overloaded and those with light loads, it can be done with the help of the Distribution Substation Information System (SIGD) software. By selecting overload transformer data and low-load transformer data, a list of the required distribution transformers will appear. This transformer list will be arranged based on the percentage of the transformer load, then grouped into the first group, namely Distribution Transformers with a load above 80% and the second group, namely Distribution Transformers with a load below 50%. This grouping is done to try to estimate the distribution transformer uprating planning route that will be arranged. After being divided into two groups, the next step is to select the overloaded transformer to be uprated. Then for its replacement, a transformer with a low load is selected. In the implementation of distribution transformer uprating, in addition to being uprated with a low-load transformer that is still operating, a transformer can also be uprated with a new transformer if there is availability of goods. In the implementation of transformer uprating, the transformer should have the same phase as the distribution transformer that will be uprated, for example a three-phase distribution transformer is uprated with a three-phase distribution transformer as well. In addition to using SIGD software, transformer uprating activities can also be carried out if there is a request from consumers who are usually consumers with large power consumption such as companies and other agencies. An important thing to consider in selecting a distribution transformer to be uprated is the distance between the transformers to be uprated. If the location of the two transformers is too far apart,then it will take a long time in the implementation of the transformer uprating and will disrupt the availability of electricity for customers. Therefore, it is attempted to find a distribution transformer that is close to minimize the time of transformer uprating activities.

Table 1 Transformer overload and underload specifications

Transformer Specifications	Transformer Overload	Transformer Underload
Rayon Card	JH-400	JH-274
Location	Jl.	Jl. Sidodadi
Power (kVA)	100	160
Phase	3	3
Brand	TRAFINDO	TRAFINDO
WBP Burden Before Uprating: kVA	99.76 kVA	52 Kva
WBP Burden Before Uprating :	99.77%	32%

The JH-400 distribution transformer is located on Jl. Eka Budi which distributes electrical energy to consumers from medium voltage 20 kV to 400/230V. The JH-400 transformer is a general transformer provided for general customers, where the distribution transformer used is a three-phase distribution transformer with a capacity of 100 kVA with the TRAFINDO brand. The JH-400 distribution transformer is supplied from the NR.04 feeder originating from the Namorambe Main Substation. The JH-274 distribution transformer is located on Jl. Sidodadi which distributes electrical energy to consumers from a medium voltage of 20 kV to 400/230V. The JH-274 transformer is a general transformer provided for general customers, where the distribution transformer used is a three-phase distribution transformer with a capacity of 160 kVA with the TRAFINDO brand. The JH-400 distribution transformer is supplied from the NR.04 feeder originating from the Namorambe Main Substation.

Uprating The transformer to be uprated is the transformer uprating from JH-274 to JH-400 transformer. The selection of the transformer to be uprated is based on several requirements for distribution transformer uprating so that the distribution transformer uprating can run effectively and efficiently. In addition, what needs to be considered in selecting the transformer to be uprated is the location of the two distribution transformers. The transformer to be uprated should not be too far away, so that the transformer uprating work can be done in a shorter time. After conducting a location survey and considering the load percentage, the JH-400 distribution transformer was selected for transformer uprating. The transformer uprating was carried out on Thursday, August 11, 2022. The JH-274 transformer located on Jl. Sidodadi and the JH-400 transformer located on Jl. Eka Budi, The distance between these two distribution transformers is approximately 1 km so that it is possible to carry out distribution transformer uprating activities.

Table 2. JH-400 Distribution Transformer Specifications

Substation Code-No Transformer	JH-400
Location	Jl.
Feeder	NR.04
Power (kVA)	100
Tap Position	3/3
Phase	3

Table 3. JH-274 Distribution Transformer Specifications

Substation Code-No Transformer	JH-274
Location	Jl. Sidodadi
Feeder	NR.04
Power (kVA)	160
Tap Position	3/3
Phase	3
Serial No.	-
Brand	TRAFINDO
Primary Voltage LL (kV)	20
Secondary Voltage LL (V)	400
Primary Current (Amps)	2.9
Secondary Current (Amps)	144.3
Types of Oil	Diala B
Construction	Double Pole

Table 4 . Distribution Transformer Load Data JH-400 Before Uprating Is 100 kVA

LWBP	OUTGOING EAST	OUTGOINGWEST	INCOMING Amp	INCOMING %
R (Amp)	1	83	84	58
S (Amp)	2	81	83	58
T (Amp)	15	98	115	80
N (Amp)	15	39	52	
Burden (%)	4	58		
WBP	OUTGOING EAST	OUTGOINGWEST	INCOMING Amp	INCOMING %
R (Amp)	1	129	131	91
S (Amp)	1	135	136	94
T (Amp)	30	134	165	114
N (Amp)	29	56	71	
Burden (%)	7	88		
Cos φ	0.8		99.76 KVA	99.77%

From Table 4 it can be seen that the percentage of transformer load on the JH-400 has reached 99.77% and is considered overloaded so that maintenance is needed.

Table 5. Distribution Transformer Load Data JH-274 Before Mutation Is 160 kVA

LWBP	OUTGOING EAST	INCOMING (Amp)	INCOMING (%)
R (Amp)	60	60	26
S (Amp)	11	11	5
T (Amp)	70	70	30
N (Amp)	49	49	
Burden (%)		33	20
WBP	OUTGOINGEAST	INCOMING Amp	INCOMING %
R (Amp)	81	81	35
S (Amp)	23	23	10
T (Amp)	121	121	52
N (Amp)	83	71	
Burden (%)		52	32
Cos $_{\varphi}$	0.8	52 kVA	32%

In Table 5, the JH-274 distribution transformer load data before being transferred is still very low because the loading percentage is still 32%. From Table 6, it can be seen that the percentage of transformer load on JH-274 has increased from the initial 32%, now after the transformer mutation has been carried out it has become 61.20% and is no longer classified as an underload transformer.

Table 6 Distribution Transformer Load Data JH-274 After Mutation From 160 kVA To 100 kVA

LWBP	OUTGOINGEAST	INCOMING Amp	INCOMING %
R (Amp)	57	57	40
S (Amp)	69	69	48
T (Amp)	67	67	46
N (Amp)	28	28	
Burden (%)		45	45
WBP	OUTGOINGEAST	INCOMING Amp	INCOMING %
R (Amp)	87	87	60
S (Amp)	93	93	64
T (Amp)	85	85	59
N (Amp)	48	48	
Burden (%)		61.19	61.20
Cos $_{\varphi}$	0.8	61.19 kVA	61.20%

Table 7 Distribution Transformer Load Data JH-400 After Uprating From 100 kVA To 160 kVA

LWBP	OUTGOINGEAST	OUTGOINGWEST	INCOMING Amp	INCOMING %
R (Amp)	85	43	128	55
S (Amp)	26	45	71	31
T (Amp)	75	44	119	52
N (Amp)	55	11	57	
Burden (%)			73	46
WBP	OUTGOINGEAST	OUTGOINGW ST	INCOMING Amp	INCOMING %
R (Amp)	88	19	107	46

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LWBP	OUTGOINGEAST	OUTGOINGWEST	INCOMING Amp	INCOMING %
S (Amp)	41	3	44	19
T (Amp)	92	40	132	57
N (Amp)	53	36	88	
Burden (%)			65.35	40.84
Cos φ	0.8		65.35 KVA	40.84%

From Table 7, it can be seen that the percentage of transformer load on the JH-400 has decreased, which initially reached 99.77%, now after the transformer uprating has been carried out it has become 40.84% and is no longer classified as an overload transformer.

RESULTS AND DISCUSSION

Data Analysis of JH-400 Distribution Transformer Before Uprating Which Has a Capacity of 100 kVA.

Determining the distribution transformer load A 3-phase transformer with a capacity of 100 kVA with a power factor set by PLN based on SPLN 70-1 regulation is >0.85 with a voltage of 400 V. This means that based on the formula, S = √3 x V x I, the maximum current that can be supplied is

- $S = \sqrt{3} \times V \times I$
- $I = S / (\sqrt{3} \times V)$
- $I = 100{,}000\ VA / (\sqrt{3} \times 400)$
- $I = 144\ A$

From the results of the solution above, the transformer is loaded 100% at a current of 144 A. In the power triangle formula, the P value for three phases is calculated from:

- $P = \sqrt{3} \times V \times I \times \cos\varphi$

Since S for three phases is = √3 x V x I, then P can be simplified to P = S xCos φ. The capacity of a transformer to fill a certain load must be with its VA (S), but at what power P (kW) a transformer can be loaded 100% depends on the magnitude of the power factor value caused by the nature of the load it will supply. Maximum valueCos φ or power factor is 1, namely at angle $\varphi = 0^o$ in the power triangle, where the value of Q = 0, so that S = P. This is in accordance with the rules of trigonometry, Cos 0^o = 1. When the load displayed by the transformer is inductive or capacitive, the value of Q will change, so that the angle φ will be formed, enlarged or reduced according to the value of Q. The angle φ formed is in the range of 0^o-90^o. So that the value of Cos φ (power factor) is in the range of 1-0. Now, if the power factor of the load is at a certain value, then 100% of the transformer capacity to load the load is, as follows: If the value of Cos φ = 0.85, then 100% of the transformer capacity is at the power:

- $P = S \times \cos\varphi$
- $P = S \times 0.85$

In JH-400 has a capacity of 100 kVA, then 100% of the transformer capacity is at power:

- $P = S \times \cos\varphi$

- P = 100,000 VA x 0.85
- P = 85,000 Watts
- P = 85 kW

This means that, at a load of 85 kW with a power factor of 0.85, the 100 kVA transformer is 100% loaded, because the current flowing by the transformer is its maximum current, namely 144 A (S = √3 x V x I).

a. Determining FCO on a 100 kVA transformer
   To determine the size of the fuse cut out, we first calculate the nominal current on the primary side of the transformer using the following equation:

$$\text{In Teg.Primer} = \frac{s}{\sqrt{3}x\ v} = \frac{100\%}{\sqrt{3}x\ 20\text{kV}} = 2.89\text{ A}$$

   So the Fuse Link rating that will be used is 4 A.

b. Determining the NH Fuse on a 100 kVA transformer
   To determine the size of the NH Fuse, the nominal current on the secondary side of the transformer must be calculated using the following equation:

$$\text{In Teg.Secondary} = \frac{s}{\sqrt{3}x\ v} = \frac{100\%}{\sqrt{3}x400V} = 144\text{ A}$$

After being calculated using the formula, the percentage of load on the transformer was obtained and the results showed that the JH-400 transformer was overloaded because the total percentage of the transformer load was 99.77%. A transformer is said to be overloaded if it exceeds 80% of its capacity.

Transformer Measurement Data Before Mutation from JH-400 to JH-274

The following are the measurement results on the distribution transformer experiencing underload on the JH-274. JH-274 Transformer Data (Wednesday, August 10, 2022) 18.00-22.00 WIB

Table 7. Transformer Measurement Data Before Mutation

WBP	OUTGOIN EAST	INCOMING Amp	INCOMING %
R (Amp)	81	81	35
S (Amp)	23	23	10
T (Amp)	121	121	52
N (Amp)	83	71	
Burden (%)		52	32
Cos $_{\varphi}$	0.8	52 kVA	32%

Table 7 shows the results of measuring the JH-400 transformer load before uprating.

1. Measurement data that was carried out on Wednesday, August 10, 2022 at 18.00-22.00, namely Peak Load Time (WBP), Incoming loading on the R phase was 81A, the S phase was 23A, and the T phase was 121A.
2. The measurement results data for the Peak Load Time (WBP) of the East Route loading on the R phase is 81A, the S phase is 23A, the T phase is 121A.
   Judging from the measurement results that have been carried out, it shows that the

JH-274 transformer is underloaded because the total percentage of the transformer load is 32.47% and has a loading capacity of 52 kVA. A transformer is said to be underloaded if the load is below 50% of its capacity.

JH-400 Distribution Transformer Data Analysis After Uprating Has a Capacity of 160 kVA

Determining the distribution transformer load A 3-phase transformer with a capacity of 160 kVA with a power factor set by PLN based on SPLN 70-1 regulation is >0.85 with a voltage of 400 V. This means that based on the formula, S = √3 x V x I, the maximum current that can be supplied is:

- S = √3 x V x I
- I = S / (√3 x V)
- I = 160,000 VA / (√3 x 400)
- I = 231 A

From the results of the solution above, the transformer is loaded 100% at a current of 231 A. In the power triangle formula, the P value for three phases is calculated from:

- P = √3 x V x I xCos φ

Since S for three phases is = √3 x V x I, then P can be simplified to P = S xCos φ. The capacity of a transformer to fill a certain load must be with its VA (S), but at what power P (kW) a transformer can be loaded 100% depends on the magnitude of the power factor value caused by the nature of the load it will supply. Maximum valueCos φ or power factor is 1, namely at angle φ = 0^o in the power triangle, where the value of Q = 0, so that S = P. This is in accordance with the rules of trigonometry, Cos 0^o = 1. When the load displayed by the transformer is inductive or capacitive, the value of Q will change, so that the angle φ will be formed, enlarged or reduced according to the value of Q. The angle φ formed is in the range of 0^o-90^o. So that the value of Cos φ (power factor) is in the range of 1-0. Now, if the power factor of the load is at a certain value, then 100% of the transformer capacity to load the load is, as follows: If the value of Cos φ = 0.85, then 100% of the transformer capacity is at power:

- P = S x Cos φ
- P = S x 0.85

In JH-400 has a capacity of 160 kVA, then 100% of the transformer capacity is at power:

- P = S x Cos φ
- P = 160,000 VA x 0.85
- P = 136,000 Watts
- P = 136 kW

This means that, at a load of 136 kW with a power factor of 0.85, the 160 kVA transformer is 100% loaded, because the current flowing by the transformer is its maximum current, namely 231 A (S = √3 x V x I). After calculating using the formula, the percentage of load on the transformer was obtained and the results showed that the JH-274 transformer had returned to normal or was not experiencing underload because the total percentage of transformer loading was no longer below 50% of the transformer capacity, which was 61.20%.

Data analysis

Based on the provisions that have been set, the permitted load on a transformer is 80% of the transformer capacity So the JH-400 transformer is declared as an overload transformer due to the percentage of loading exceeding the provisions, namely 99.77%, d carrying out mutations on the JH-274 transformer whose loading is below 50% of its capacity.

So the JH-400 transformer is declared as an overload transformer due to the percentage of loading exceeding the provisions, namely 99.77%, and carrying out mutations on the JH-274 transformer whose loading is below 50% of its capacity. To maintain the continuity of electricity distribution and quality of service to customers, PT PLN (Persero) ULP Medan Johor took action to make repairs as appropriate to overcome overload and underload conditions of a transformer. However, in this study, the author only conducted an analysis of a transformer to overcome these conditions, and the object of this study was centered on the JH-400 and JH-274 transformers that experienced overload and underload. Based on the author's calculation results, it can be seen in the diagram below that there is a percentage change per phase before and after the JH-400 transformer uprating is carried out. Before the uprating, the percentage results per phase of the JH-400 were:

Table 8. Data Percentage Load Each Phase

BEFORE UPRATING	AFTER UPRATING
IR = 90.07%	IR = 46.33%
IS = 94.22%	IS = 57%
IT = 113.6%	IT = 38.53%

Based on the results of the Author's research, overload on a transformer can be overcome by uprating and installing an insert transformer. However, in overcoming overload on the transformer on the JH-400, Uprating is carried out, this is done to improve the overload and also the voltage drop on the transformer. From the calculation results on the JH-400 Transformer before the transformer uprating, the percentage loading results obtained were 99.77%. However, after the transformer Uprating, the loading results on the transformer changed. It can be seen that the percentage loading value on the JH-400 transformer has changed after carrying out Transformer Uprating so that the initial loading value of 99.77% becomes 40.84%, so it can be said that there has been a decrease in the percentage loading of 58.93%. Based on the author's calculation results, it can be seen in the diagram below that there is a percentage change per phase before and after mutation was carried out on the JH-274 transformer.

CONCLUSION

Excessive loading on transformers can be overcome by carrying out Uprating activities so that the risk of damage caused by excessive loads can be overcome. By carrying out transformer Uprating maintenance, the percentage of loading at the JH-400 substation

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decreased from 99.77% to 40.84%. By reducing the load percentage, the transformer's life time will be longer, up to 20 years. The percentage of transformer load on JH-274 has increased from the initial 32% (underload) after the transformer mutation was carried out to 61% and is no longer classified as an underload transformer.

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