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TRANSFORMER LIFE-CYCLE COSTING ANALYSIS

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ABSTRACT

TRANSFORMER LIFE-CYCLE COST ANALYSIS IS A METHOD FOR ASSESSING THE TOTAL COST OF TRANSFORMER IN ITS ENTIRE USEFUL LIFE. IT CONSIDERS ALL COSTS OF ACQUIRING, OWNING (ENTIRE OPERATION AND MAINTENANCE COST). LIFE CYCLE COST ASSESSMENT IS ESPECIALLY USEFUL TO IDENTIFY CHEAPEST LIFE CYCLE COST TRANSFORMER FROM THE ALTERNATIVES OFFERED BY SUPPLIERS INSTEAD OF ACQUIRING COST. LIFE CYCLE COST ASSESSMENT TAKES VITAL TECHNICAL INPUTS OFFERED BY THE SUPPLIERS UNDER TECHNICAL BID CONVERTS THEM INTO COST COMPONENTS AND ADDS TO COMMERCIAL PRICES OF TRANSFORMER, INSTALLATION CHARGES, ETC TO ARRIVE AT LIFE CYCLE COST. SUITABLE ASSUMPTION ARE MADE FOR ENERGY PRICES, INSULATING OIL PRICES, EXPECTED ESCALATION YEAR ON YEAR BASIS. THE PRESENT VALUE METHOD OF FUTURE CASH FLOWS IS USED TO CONVERT FUTURE CHARGES TO BE SPENT ON MANITENANCE OF TRANSFORMER WITH SUITABLE ASSUMPTION OF DISCOUNTING RATE.

THE PAPER CONSIDERS ALL TECHNICAL PARAMETERS OF TRANSFORMER, CLASSIFY THEM INTO USEFUL OR NOT USEFUL WITH REASONING FOR LIFE CYCLE ANALYSIS. AS THE MAITENANCE PRACTICES DIFFER FROM USER TO USER BASED ON THEIR EXPERIENCE, SOME OF THE ASSUMPTIONS CAN BE CHANGED EASILY, THAT IS EXPLAINED UNDER EACH COST COMPONENT.THE METHOD OF CONVERTING INTO COST IS EXPLAINED ON THE BASIS OF LARGE UTILITY TRANSFORMER. ONE SAMPLE TRANSFORMER ANALYSIS IS ENCLOSED, THAT SHOWS CHEAPER TRANSFORMER MAY NOT BE CHEAPEST LOWEST LIFE-CYCLE COST TRANSFORMER.

INTRODUCTION

Transformer Life-cycle cost analysis is a method for assessing the total cost of transformer in its entire useful life. It considers all costs of acquiring, owning (entire operation and maintenance cost), and disposing of after its useful life. Life Cycle Cost assessment is especially useful to identify cheapest life cycle cost transformer from the alternatives offered by the suppliers. Life Cycle Cost assessment requires guaranteed technical parameters, commercial prices of transformer, installation charges, energy prices, insulating oil prices, expected escalation year on year basis and assumptions based individual owner experience. The commercial price offers differ with respect to initial costs, transport and installation charges and different suppliers quote different prices worked out on material cost, service cost, their margin and their perception on the customer. The operating and maintenance costs, to be worked out and added to the commercial offers to arrive at the life cycle cost and select cheapest life cycle cost transformer, that maximizes net savings over entire life period. Life Cycle Cost will help determine the optimal required performance transformer for the desired application, which may be at higher initial cost but result in dramatically reduced operating and maintenance costs. Life Cycle Cost is not useful for budget allocation.

Lowest life-cycle cost is the most straightforward and easy-to-interpret measure of economic evaluation. Some other commonly used measures are Net Life Savings or Net Life Benefits, Internal Rate of Return, Payback Period, warranty for the life time. They are consistent with the Lowest Life Cycle Cost measure of evaluation if they use the same parameters and length of study period. Economists, certified value specialists, cost engineers, architects, quantity surveyors, operations researchers, and others might use any or several of these techniques to evaluate transformer cost. The life cycle cost also can be compared with comprehensive offer for the supply, installation, commissioning and life time (25 years after installation) maintenance inclusive of all spares and service with well specified response time. The comprehensive offer can be considered with correct payment terms if it is below or equal to the adjusted life cycle cost for the energy consumed during the life.

TRANSFORMER LIFE-CYCLE COST ANALYSIS FUNDAMENTALS

Transformer is very vital and costlier electrical equipment in generating and substation. Transformer failure lead to either generation loss or transmission capacity loss, hence it is preferable to reduce its failure or increase its life to possible extent. Preference for least life cycle cost transformer is better than least purchase price transformer. Any reduction in transformer cost reduces project cost.

The components considered for life cycle costing are i) No load losses ii) load losses iii) Installation & Commissioning time iv) Space required v) auxiliary losses like radiator cooling fans and oil pumps vi) Cost of recommended spares for 5 year maintenance vii) Oil condition monitoring, top ups and replacement viii) Time for which transformer can be operated at full load after failure of cooling fans and pumps ix) Maximum Flux Density at rated voltage and frequency x) Over flux withstand capability

The components not considered for life cycle costing at this stage and can be finetuned later are i) % Impedance Voltage at rated power ii) Maximum temperature rise at rated power with ambient of 40^{o}C iii) Limit of hot spot temperature iv) Design current density v) Guaranteed Capacitance and Dissipation Factor vi) Maximum Partial Discharge vii) Guaranteed Bushing parameters viii) Conservator Oil Preservation System ix) Oil parameters x) Winding Resistance xi) Routine Maintenance carried out regular intervals xii) Noise Level xiii) Core Material properties xiv)Inrush current xv) Transport Charges xvi) On load tap changer step size and nos xvii) Overload transformer capacity xviii).Energy consumed by heaters and lights

ANALYSIS OF COMPONENTS NOT CONSIDERED LIFE-CYCLE COST ANALYSIS

i) % Impedance Voltage at rated power

The % Impedance Voltage of the transformer plays a role in sharing of load and fault contribution. The highest value preferred to limit the fault contribution and lowest value preferred to reduce the losses. This parameter is normally chosen from the existing transformers and the transmission system to match with the existing system. The positive or negative tolerance plays a little role, hence not considered at this stage.

ii) Maximum Temperature rise at rated power with ambient of 40^{0}C

Higher the maximum temperature rise leads to increase in winding resistance with associated losses and additional auxiliary power consumption due to burden on cooling system. The quantification is little complex, hence not considered at this stage.

iii) Limit of hot spot temperature

Higher the limit reduces probability of overloading, operation under higher ambient temperatures, increases probability of high winding and oil temperature trips. It shows the transformer is designed too optimally with little inefficient cooling. The quantification is little complex, hence not considered at this stage.

iv) Design current density

Higher design current density shows little lesser size of winding wires and increases probability of transformer failures due to feeding prolonged through faults. If the protection system is fast and selective, the transformer may not come under stress, can live longer, hence not considered at this stage.

v) Guaranteed Capacitance and Dissipation Factor

This depends on quality of insulation material used, higher the capacitance better as the transformer is basically inductive and provides better compensation. Higher the dissipation factor shows inferior quality of insulation and causes additional loss. The losses are insignificant and not considered at this stage.

vi) Maximum Partial Discharge

Partial discharges occur normally at radio or little higher frequencies and causes interference with communication. Higher value shows inferior quality of insulation and to be monitored on regular basis to monitor trends. Constant values within the permitted band can be tolerated, but the regular increase in values indicate the insulation deterioration. Losses caused by the discharges are insignificant and not considered at this stage.

vii) Guaranteed Bushing parameters

There are few EHV bushing manufacturers across the world and the user can always specify better quality bushings. The bushings should have test tap facility for condition monitoring. Due to very small capacitance of the bushing, very high dissipation factor gets diluted with high capacitance of the transformer. We are discussing EHV, large capacity transformers, this component is not considered due to its insignificance.

viii) Conservator Oil Preservation System

Currently all transformers above 10MVA capacity are inbuilt with Conservator Oil Preservation system to allow expansion or contraction of oil caused by ambient changes with no contact to external atmosphere. The system provides high dielectric integrity, positive static pressure on unit, reduced maintenance, allow Buccholz relay to collect accumulated gases effectively. Due to incorporation of this system on all transformers, this component is not considered.

ix) Oil parameters

Transformer insulating oil is supplied by different suppliers priced on oil grades. The customer can select oil grade, request the supplier to provide as preferred. This component is not considered as oil can be same from different transformer manufacturers.

x) Winding Resistance

Larger value winding resistance will result in larger losses, smaller value requires larger volume of copper. As all suppliers prefer optimum design, the resistance value deviation among different suppliers is normally insignificant, hence this component not considered.

xi) Routine Maintenance carried out regular intervals

The routine maintenance activities exclude condition monitoring activities, includes activities like regular inspection, cleaning of bushings, Buccholz relay, Oil gauge, Pressure Relief Device, attending to traces oil seepage etc. Such activities are taken up by all utilities in line with established practices. This component is not considered due to its insignificance as they are predominantly governed by the practices.

xii) Noise Level

Every supplier designs transformer to produce noise within the permitted level decided by the respective Country Regulations. This component not considered as all suppliers will be within permitted levels.

xiii) Core Material properties

We are discussing large capacity transformers, that can be designed with best core material. Cutting, clamping of core laminations plays an important role with the material and the entire core condition can be judged after the transformer takes final shape. The deviations among the suppliers on this account are normally insignificant, hence not considered.

xiv) Inrush current

When transformer is energized, it draws huge current which is not sinusoidal, dies down in few cycles. Lesser magnitude is preferable; hence transformer is normally energized from HT side except Generator Step Up transformers. In case of generator step up transformers, the excitation system builds up voltage slowly to reduce the evil effects. As the quantification is complex, this component is not considered at this stage. It is preferable to select transformer with inrush current not more than six times of full load current. Supplier will design transformer to be energized from LT side with necessary precaution.

xv) Transport Charges

The transport charges depends on transport medium like Road, Rail, Ship or Air and the distance between works and the project location. The packing and forwarding is decided by the supplier and it is preferable to request for the offers up to the project location. Hence the transport charges are not considered.

xvi) On load tap changer step size and nos

On load tap changer step size and the numbers are to be decided by the user depending on the application and system conditions. The parallel operation to be specified by the user. There are few on load tap changer manufacturers for EHV transformers across the world, and the customer can specify the preferred one. Hence this component not considered.

xvii) Overload transformer capacity

User is free to specify, needed overload capacity of the transformer. Some standards specify overload capacity, and the user can refer that standard. Any overload capacity will increase transformer size and price. As the user is free to specify correct requirement, this component is not considered.

xviii) Energy consumed by heaters and lights

There are heaters and lights installed in the transformer marshalling box, cooler cabinet and they consume energy. The heaters operate depending on the ambient conditions and operational settings. The lights operate during inspection and maintenance purposes. The energy consumed is insignificant and not considered.

ANALYSIS OF COMPONENTS CONSIDERED FOR LIFE-CYCLE COST ANALYSIS

i) No load losses

No load loss is the energy consumed by the transformer with one side energized and another side not connected to the load. The energy can easily be quantified from the guaranteed values furnished by the supplier. The annual energy consumed on this account to be estimated on the basis of 90% time transformer remains energized as under:

Guaranteed no load loss furnished by the supplier = 50kW
Energy consumed on this account = 50x365x0.90x24 = 394,200 kwh or units

Cost on this account can be computed from the average energy prices in USA and can be safely assumed at 10 cents (10¢) with year on year escalation at 3%. In India the energy cost per unit can be easily assumed at Rs 4/- with year on year escalation at 7%. The cost of annual energy consumed on this account can be computed as under:
Cost of energy consumed in a year on "No load Losses account" = 392,200x0.1= $ 39,220

The present value of energy consumed for the entire 25 year life period can be computed on present value method of future cash flows with assumption of discounting rate which is risk free interest rate on deposits. In USA context, 5 year treasury bill rate (currently @ 2.50%) is considered for discounting rate and in Indian Context, SBI, interest rate (currently @6.5%).

The present value of cash flows due to energy consumed on "No load losses" for 25 year life cycle can be computed (In USA context) as under:

$$\text{Life Cost No load losses} = 39{,}220\left(1+\frac{(1+0.03)}{(1+0.025)}+\frac{(1+0.03)^2}{(1+0.025)^2}+\frac{(1+0.03)^3}{(1+0.025)^3}+\cdots+\frac{(1+0.03)^{24}}{(1+0.025)^{24}}\right)$$
$$= 1{,}040{,}100\ \$$$

If the average escalation (over the past period of 5 years) rate of energy cost is less than risk free interest rate or the discounting rate, then current annual energy charges are to be multiplied by 25, instead of present value of cash flows method.

ii) Load losses

Load loss is the energy consumed by the transformer, when it carries load. The load losses are proportional to the load fed by the transformer. Distribution transformer load normally changes over the day and the generator step up transformer feeds fixed load that is capacity of the generator to which it is connected. Hydro generators normally feed during peak hours and thermal generators feed the base load throughout the day.

Due to the redundancy built in transmission and distribution system, large transmission and distribution transformers designed to carry 50% under normal conditions and 100% under emergency operating conditions. The generator step up transformers are normally designed to carry 90% of its capacity. Hence on average, it can be easily assumed to carry 60% load under all conditions.

The energy consumed on account of load losses can easily be quantified from the guaranteed values furnished by the supplier. The annual energy consumed on this account to be estimated on the basis of 60% capacity as discussed above, and the transformer remains energized for 90% time as under:

Guaranteed full load loss furnished by the supplier = 330kW
Energy consumed on this account = 330x0.60x365x0.90x24 = 1,561,032 kwh or units
Cost of energy consumed in a year on "Load Losses" = 1,561,032x0.1= $ 156,103

The present value of cash flows due to energy consumed on "Load losses" for 25 year life cycle can be computed (In USA context) in a similar way as computed for "No Load Losses" we discussed earlier:

$$\text{Life Cost Load Losses} = 156{,}103\left(1+\frac{(1+0.03)}{(1+0.025)}+\frac{(1+0.03)^2}{(1+0.025)^2}+\frac{(1+0.03)^3}{(1+0.025)^3}+\cdots+\frac{(1+0.03)^{24}}{(1+0.025)^{24}}\right)$$
$$= 4{,}139{,}796\ \$$$

If the average escalation (over the past period of 5 years) rate of energy cost is less than risk free interest rate or the discounting rate, then current annual energy charges are to be multiplied by 25, instead of present value of cash flows method.

iii) Installation & Commissioning Time

Large size transformers are installed under the supervision of expert deputed by the manufacturer or installed and commissioned by the manufacturer either through a turn key contract or supply and services contract to ensure the transformer is installed correctly and to make the warranty effective. If the transformer is installed earlier, the revenue starts early and if delayed revenue gets delayed.

Installation and commissioning time quoted by different suppliers to be converted into money to evaluate them correctly. The time is estimated as under:

Cost incurred on transformer with installation & commissioning = 2 million $
Equity by the owner @30% = 0.3x2 =0.6 million $
Quoted Installation & Commissioning Time = 100 days
Cost of equity @ 12% for 100 days = 0.6x0.12x100/365 = 0.0197 mn $ or 19726 $

Here the assumption is rest 70% component is financed through debt and the actual interest on debt is reimbursed from the revenues. The actual equity-debt ratio and the interest rates can be used to arrive at the actual values. The cost of installation and commissioning time in the above case works out to 19,726 $.

iv) Space Required

Transformer size depends on the design. Compact or optimal size transformers are preferred due to the cost involved on the space occupied by the transformer. Estimation on this account is very simple and computed as under:

Cost of land/m^2 = 10 $
Space Required for the transformer = 100m^2
Cost of space required = 100x10 = 1000$

The space required should include the entire transformer, radiators, burnt oil tank, fire protection walls etc.

v) Auxiliary losses: Radiator cooling fans and oil pumps

Auxiliary loss is the energy consumed by the transformer for the operation of cooling system. The cooling system normally consists of radiator fans to cool the oil in the radiator and oil pumps to circulate the oil through the ducts inside the transformer. The winding gets heated up due to the current flow and in turn heats the insulating oil. The cooling system removes the heat and keeps winding within designed temperature band. The pumps circulate oil and reduces the temperature spread between top and bottom oil. The fans cool oil that is inside radiators. Hot oil normally reaches the radiator at the top from transformer tank, cool oil from radiator bottom pushed into the tank either through oil pumps or through natural convection currents.

In case of compact design with oil circulating ducts (ODAF= Oil Directed Air Forced), the cooling system must run continuously when energized and in the conventional design the pump and fans are set to run depending on Oil and Winding Temperatures. Hence transformers designed with “Nil” ONAN (Oil Natural Air Natural) capacity rating, the losses to be calculated on 100% basis and ONAN rated transformers on 80% basis, as the transformer is loaded lightly within ONAN rating at least 20% of its life.

The energy consumed because of cooling system can easily be quantified from the guaranteed values furnished by the supplier. The annual energy consumed on this account to be estimated with the transformer energized for 90% time as under:

Guaranteed auxiliary losses at rated output with ambient at 40^{o}C = 4 kW
Energy consumed on this account = 4x0.8x365x0.90x24 = 25,229 kwh or units
Cost of energy consumed in a year on “Load Losses” = 25,229x0.1= $ 2,523

The present value of cash flows due to energy consumed on “Auxiliary Losses” for 25 year life cycle can be computed (In USA context) in a similar way as earlier:

$$\text{Life Cost Auxiliary Losses} = 2{,}523\left(1+\frac{(1+0.03)}{(1+0.025)}+\frac{(1+0.03)^2}{(1+0.025)^2}+\frac{(1+0.03)^3}{(1+0.025)^3}+\cdots+\frac{(1+0.03)^{24}}{(1+0.025)^{24}}\right)$$
$$= 66{,}909\ \$$$

If the average escalation (over the past period of 5 years) rate of energy cost is less than risk free interest rate or the discounting rate, then current annual energy charges are to be multiplied by 25, instead of present value of cash flows method.

vi) Cost of recommended spares for 5 year maintenance

Recommended spares to maintain the transformer depends on grid conditions, application and regular maintenance carried out by the user. Suppliers are expected to understand the conditions and offer to maintain the transformer. With the external conditions remaining same for all the suppliers, the spares offered for 5 year maintenance provide clue to their design. It will be better to obtain comprehensive offer for 5 year maintenance with material and. Such offer will be little complex.

Our assumption at this stage is procured spares will be utilized in 5 year period and to be replenished at the end of 5th year. Transformer will be fully maintained by the user, with necessary expert supplier supervision services apart from own staff. Transformer will require at least one major overhaul like replacement of entire oil, bell tank removal, inspection of core-coil assembly, extraction of paper for furfural test to assess the remaining life. Let us assume this overhaul is taken up at the end of 15th year and we will not take up any other major overhaul as life period considered is 25 years. Replacement cost of oil will be quantified under oil top ups and here let us quantify only spares other than oil, core and coil.

Spares escalation on year on year basis can be safely considered at 5% and the cost of major overhaul to be considered at 32% cost (Initial Cost of Transformer with oil or 40% cost without oil) of the transformer. The present value of life cost of spares to maintain transformer can be computed as under:

Quoted price for total transformer = 1,750,000
Quoted Spares price for 5 year period = 125,000 $
Present Value of spares required at 1st, 5th, 10th, 20th year can be computed as:

$$125{,}000\left(1+\frac{(1+0.05)^5}{(1+0.025)^5}+\frac{(1+0.05)^{10}}{(1+0.025)^{10}}+\frac{(1+0.005)^{20}}{(1+0.025)^{20}}\right) = 627{,}471\ \$$$

Present Value of major overhaul = $0.32 \times 1{,}750{,}000/(1+0.025)^{15}$ = 386,660 $
Life cost of recommended spares = 627,471+386,660 = 1,014,132 $

vii) Oil condition monitoring, top ups and replacement

Transformer is filled with insulating oil up to desired conservator level. Over period oil evaporates, seeps through leakages leading to drop in oil level. Oil leakages developed over period cannot be attended and may be require major overhaul. Condition of the insulating oil to be monitored on regular basis and immediately after through faults. Oil samples are taken out through sampling devices installed in the transformer twice a year and sent for tests. When condition of the oil deteriorates, filtering is taken up and the filtration process results in loss of small quantity.

The oil losses due to evaporation, leakages, filtration losses can easily be assumed at 1% for five years period and has to be topped up may be once in 5 years. In case of major overhaul, that we have assumed in 15th year, the total oil gets replaced with new oil. The cost of condition monitoring, filtration, top ups and oil replacement can be easily estimated from the values indicated by the supplier at the design stage and the cost of oil. The present value of cash flows method allows us to estimate the present value on oil monitoring, filtration, top ups and replacement over transformer life cycle.

At least five oil samples are required to be tested at the time of commissioning and at oil replacement (Sample from top up drums, after filling, after filtration, before energization, 24hrs after energization), then one sample twice a year. The cost of tests, oil cost are escalated year on year basis at 5% and same discounting factor as earlier are used.

Total volume of oil (litres) = 35,000
Price of oil/litre = 1.50 $
Price of oil tests (DGA, BDV, Chemical Analysis)/Sample = 350 $

Present Value of oil tests can be computed as:

$$350(5+\frac{2(1+0.05)^{1}}{(1+0.025)^{1}}+..+\frac{2(1+0.05)^{14}}{(1+0.025)^{14}}+\frac{5(1+0.05)^{15}}{(1+0.025)^{15}}+\frac{2(1+0.05)^{16}}{(1+0.025)^{16}}+..+\frac{2(1+0.005)^{24}}{(1+0.025)^{24}})=24{,}880\ \$$$

Present Value of oil top ups and replacement can be computed as:

$$1.5(\frac{350(1+0.05)^{5}}{(1+0.025)^{5}}+\frac{350(1+0.05)^{10}}{(1+0.025)^{10}}+\frac{35000(1+0.05)^{15}}{(1+0.025)^{15}}+\frac{350(1+0.05)^{20}}{(1+0.025)^{20}})=77{,}470\ \$$$

Life cost of oil condition monitoring, top ups and replacement = 24,880+77,470 = 102,350 $

viii) Time for which transformer can be operated at full load after cooling system failure

Transformers of compact design are normally designed with unit system of pump and fans to realize, oil directed air forced cooling system. Such transformers cannot even remain energized without cooling system in service. The transformers that are required to operate with ONAN rating, occupy extra space and such transformers can operate at full load for some time in case of cooling system failure. The manufacturer provides rating as guaranteed technical parameters.

In case of cooling system failure, the transformers that cannot operate, trips out causing little grid disturbance and that can operate for some time, remains in service, allows maintenance staff, attend to the cooling system. If the cooling system cannot be attended, either the load is reduced to its ONAN capacity or regular outage is arranged and availed.

The entire cooling system fails due to power supply failures which can be attended back within one hour as normal back up supply arrangements are built in. If the transformer trips out, bringing back in service after preliminary investigations and co-ordination with central controlling agency consumes around 10 hours. Hence if the transformer trips out, it causes revenue loss for a day for each occurrence and if it remains in service either continues at full load or operates at reduced load leading to no revenue loss. The revenue loss depends on application; however, we consider utility transformer for the time being.

The revenue loss is either penalty imposed by the Grid Operator or the equity return loss component of the owner. On an average, one such occurrence can happen once in five years, hence in a life of 25 years, 5 days of revenue loss can be assumed. The penalty imposed by the Grid Operator depends on grid criticality. The estimation of equity return loss can be estimated as under:

Cost incurred on transformer with installation & commissioning = 2 million $
Equity by the owner @30% = 0.3x2 =0.6 million $
No of days of revenue loss in life cycle = 5 days
Cost of equity @ 12% for 5 days = 0.6x0.12x5/365 = 0.000986 mn $ or 986 $

Revenue lost on this account is small, and if affordable, it is better to go for compact design over the conventional design. In case of generator step up transformer or a single transformer feeding continuous process industry, it is preferable to prefer conventional transformer as the loss component will be huge and not affordable.

ix) Maximum Flux Density at rated voltage and frequency

Transformer core material (CRGO steel) can safely carry flux density of 1.9 Tesla without saturation and flux density above this can saturate the transformer. Smaller grids are normally subjected to frequent voltage and frequency fluctuations than larger grids. The flux density is proportional to V/f (V= Voltage, f= frequency), transformer to be designed for ±10% voltage fluctuation and ±3% frequency fluctuations and designed for 1.7 Tesla (corresponding to 1.9 Tesla at 110% voltage) at rated voltage and rated frequency. Anything below 1.7 Tesla, improves life of transformer core in turn transformer life.

Design of transformer below 1.6 Tesla will result in higher size and not preferred. The transformer designed below 1.7 but above 1.65 can be given price advantage as the supplier has to use additional core material to improve transformer life. The estimation is as under:

Cost of transformer (without installation &Commissioning)	1.75 million $
Volume of oil	35,000 Litres
Cost of transformer without oil= (1,750,000-35,000x1.5) =	1,697,500 $
Cost of transformer material @60% = 0.6x1,697,500 =	1,018,500 $
Cost of core material @40% of material = 0.4x1,018,500 =	407,400 $

Transformer designed to operate at 1.73 Tesla at rated voltage, rated frequency.
Estimated additional Price for above 1.7 Tesla = (1.73-1.7)x407,400/1.7 = 7,189 $

Transformer designed to operate at 1.68 Tesla at rated voltage, rated frequency.
Estimated Price Discount for below 1.7 Tesla = (1.7-1.68)x407,400/1.7 = 4793 $

x) Over flux withstand capability

Over flux withstand capability plays an important role on holding capacity of transformer to the grid in case of grid disturbances when there is mismatch between generation, demand, import and export of power. Grid operator stipulates different conditions for thermal, hydro, combined cycle power plants. Grid also stipulates at what condition the station should island and for what duration the station should operate in islanded mode. Hydro station transformer is expected to come out of the grid last and expected to operate in islanded mode for longer time.

Hydro stations are operated as peak plants in most parts of the world, such transformers are subjected to major stress. We will estimate for a sample hydro transformer with given grid requirements and guaranteed technical parameters.

Technical Parameters:

Over flux withstand capability of the transformer: Continuous = 110% rated V/Hz
: 1 minute = 125% rated V/Hz
: 10 secs = 140% rated V/Hz

Grid Requirements:

Transmission voltage normal continuous range: Continuous = ±10% rated voltage

Voltage exciters should be capable of at least 1.6 times rated voltage, and should be capable of supplying ceiling voltage at least for 10 secs

Frequency range : Continuous = 49.0 – 50.4 Hz
: 3 minutes = 48.0–49.0 & 50.5-51 Hz
: 10 secs = 47.0-48.0 & 51.5-53Hz

In this case it is clear, the transformer cannot meet the condition of 1.6 times rated voltage holding on for 10 secs. All other conditions it can meet, the condition of 1.6 times can occur may be once in 10 years or maximum 3 times in its life time.

Hence if the transformer is designed to hold on more than 1.5 times rated voltage we will discount the price and less than 1.5 but above 1.25 we will add an additional cost. In case of trip out, the hydro unit can be restarted within 1 hour, hence 3 hours of generation will be lost in life time of the transformer.

Life cycle cost on Over flux withstand capability = 3x Unit Capacity x PFx Energy Price

Normal capacity of hydro transformer will be at least 110% of unit capacity with PF of 0.85

Life cycle cost on over flux withstand capability of 110MVA = 3x110,000x0.9x0.85x0.1
= 25,245 $

SAMPLE LIFE-CYCLE COST ANALYSIS OF TRANSFORMER

The following tabulation shows initial cost offers and technical parameters received from three different suppliers. The life cycle cost is computed for the three offers as explained above.

	Supplier 1	**Supplier 2**	**Supplier 3**
A: Initial Cost Offers			
1. Transformer Price	1,749,026	1,662,580	1,885,950
2. Transport Price	39,150	48,650	32,260
3. Installation&Commissioning Price	42,315	52,800	45,380
4. Spares & Consumables (5 Yrs) Price	137,146	145,890	65,280
Quoted Total Price	**1,967,637**	**1,909,920**	**2,028,870**

B: Other Offered Terms			
1. Space Required mxm	12x9	15x10	14x10
2. Installation&Commissioning Days	98	115	108
C. Technical Parameters			
1. Applicable Standard	IEC 60076 all parts	IEC 60076 all parts	IEC 60076 all parts
2. Location	Outdoor	Outdoor	Outdoor
3. No of phases	3	3	3
4. No of windings	2	2	2
5. Rated Frequency (Hz)	50	50	50
6. Rated Continuous Power ONAN/ ONAF or ODAF	Nil/115	90/115	90/115
7. Vector Group	YNd1	YNd1	YNd1
8. Ratio HV (kV)/LV (kV)	220/14.5	220/14.5	220/14.5
9. HSV HV (kV)	245	232	245
10. HSV LV (kV)	18.45	18.45	18.45
11. No-load losses @rated voltage @rated frequency @principle tap kW (max)	49.5	52.5	47.5
12. Load loss @rated output @rated frequency corrected for 75°C wdg temp:	335	350	328

13.Aux losses @rated output @rated voltage @rated frequency @40^{0}C amb temp KW	4	4.5	5
14. Time (mins) transformer can be operated at full load after failure of cooling system w/o exceeding hot spot temperature rise 140°C	0	30	60
15. % impedance voltage @rated power referred to 75°C wdg temp @principle tap	18 (±7.5%)	18 (±7.5%)	18 (±5%)
16. Design current density at nominal rating HV & LV Wdg (A/mm^2)	<3.2 at rated tap	<3.2 at rated tap	<3.1 at rated tap
17. No load current on H.V. side @rated voltage @frequency	Approx 1%	Approx 1%	Approx 1%
18. Over flux withstand capability of the transformer			
Continuous	110% of rated V/Hz	105% of rated V/Hz	115% of rated V/Hz
1 minute	125% of rated V/Hz	120% of rated V/Hz	130% of rated V/Hz
10 secs	140% of rated V/Hz	130% of rated V/Hz	145% of rated V/Hz

19. Max. flux density @ rated voltage and frequency	1.727 Tesla	1.738 Tesla	1.718 Tesla
20. Max. flux density at 110% rated voltage	1.90 Tesla	1.90 Tesla	1.90 Tesla
21. Conductor HV and LV	Copper	Copper	Copper
22. Tap Changer Range, No of steps, Step Size	±10%, 17, 1.25%	±10%, 17, 1.25%	±10%, 17, 1.25%
23. Impedance at highest tap	19.4%± 10%	19.3%± 10%	19.5%± 8%
24. Impedance at lowest tap	17%± 10%	17%± 10%	17.1%± 8%
25. Volume of Oil litres	35000	39000	38000
D. Life Cycle Cost Components			
1. No Load Losses (Annual $)	39,026	41,391	37,449
2. No Load Losses (Life Cycle $)	1,039,729	1,097,675	993,134
3. Load Losses (Annual $)	158,468	165,564	155,157
4. Load Losses (Life Cycle $)	4,202,515	4,390,698	4,114,708
5. Installation & Commissioning Time (Life Cycle $)	19,019	21,663	21,612
6.Space Required $	1,080	1,500	1,400
7. Auxiliary Losses (Annual $)	2,523	2,838	3,154
8. Auxiliary Losses (Life Cycle $)	66,909	75,263	83,643
9. Recommended Spares (Life Cycle $)	1,074,887	1,099,679	744,389
10. Oil monitoring, top ups, replacement (Life Cycle $)	102,350	111,204	108,991
11. Transformer operation under cooling system failure (Life Cycle Cost $)	986	0	0
12. Max Flux Density (Life Cycle $)	6,467	8,605	4,793
13. Over flux withsatnd capability (Life Cycle $)	25,245	25,245	25,245
E. Life Cycle Cost Estimation			
1. Transformer Price (Quoted $)	1,749,026	1,662,580	1,885,950
2. Transport Price (Quoted $)	39,150	48,650	32,260
3. Installation&Commissioning Price (Quoted $)	42,315	52,800	45,380
4. No Load Losses (Life Cycle $)	1,039,729	1,097,675	993,134
5. Load Losses (Life Cycle $)	4,202,515	4,390,698	4,114,708
6. Installation & Commissioning Time (Life Cycle $)	19,019	21,663	21,612
7.Space Required $	1,080	1,500	1,400
8. Auxiliary Losses (Life Cycle $)	66,909	75,263	83,643

9. Recommended Spares (Life Cycle $)	1,074,887	1,099,679	744,389
10. Oil monitoring, top ups, replacement (Life Cycle $)	102,350	111,204	108,991
11. Transformer operation under cooling system failure (Life Cycle Cost $)	986	0	0
12. Max Flux Density (Life Cycle $)	6,467	8,605	4,793
13. Over flux withsatnd capability (Life Cycle $)	25,245	25,245	25,245
Life Cycle Cost $	**8,369,678**	**8,595,562**	**8,061,505**

The above life cycle computation shows Supplier 3 has offered least life cycle cost transformer against the quoted price showing Supplier 2 offer is the best. The table also provides information of expected cost to be spent on the entire life cycle.

ADVANTAGES OF LIFE-CYCLE COST ANALYSIS

1. Life Cycle Cost Analysis greatly increases the likelihood of choosing a transformer that saves money in the long run.
2. Life Cycle Cost Analysis early in the design process provides an indication of cost likely to be spent on entire life cycle and allows fine tuning
3. Life Cycle Cost Analysis allows to arrive at optimal performance transformer through its entire life cycle.
4. Life Cycle Cost Analysis allows to provide better maintenance budget estimates year on year basis.
5. Life Cycle Cost Analysis provides greater informational and technical requirements than deterministic techniques.
6. Life Cycle Cost Analysis can provide technical improvements to suppliers and allow them to manufacture optimal transformers.