OPTIMIZING POWER SYSTEMS: A COMPARATIVE STUDY OF TRANSFORMER UPGRADES AND SOFT STARTERS

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https://doi.org/10.5281/zenodo.10817361

Abstract

This article explores the delicate balance between engineering considerations and operational preferences in power system projects, specifically focusing on the decision-making process regarding the use of soft starters versus transformer upgrades. The conventional reliance on soft starters is challenged, particularly in greenfield projects, where alternative solutions during the design phase may eliminate the need for soft starters altogether. The study delves into the economic feasibility and advantages of opting for larger transformers as a means to address challenges, such as voltage drops during motor startups. The article employs the Electrical Transient Analysis Program (ETAP) to construct a comprehensive model, considering factors like motor power, transformer load, and the need for soft starters. The study concludes that a higher-capacity transformer can effectively address challenges related to voltage drops and evaluates the cost implications, comparing expenses associated with larger transformers against the installation of soft starters. The article advocates for a nuanced approach in optimizing power system configurations, considering both short-term and long-term implications.

Keywords: Soft Starters, Transformer Upgrades, Power System Optimization, Voltage Drops, ETAP, Motor Starting, Comparative Analysis, High Voltage (HV), Economic Feasibility, Engineering Considerations, Operational Preferences.

Introduction

In the realm of project engineering, the decision to employ soft starters in power systems often becomes a delicate balance between engineering considerations and operational preferences. It is commonplace for project engineers to lean towards soft starters due to their ability to mitigate the high inrush currents during motor start-ups, preventing voltage dips and ensuring smoother operations.

However, the operational teams often express reservations about the widespread adoption of soft starters. Their concerns stem from the perceived difficulties and expenses associated with operating and maintaining these devices. Soft starters are seen as potential disruptors, introducing complexity that could compromise system reliability.

In the pursuit of greenfield projects, where no electrical systems are installed yet, there arises an opportunity to reassess the conventional reliance on soft starters. This article explores alternative approaches to address the challenges posed by soft starters, particularly in the context of voltage drop during motor startups.

Following aspects taken into account during the research:

- **Challenging the Soft Starter Norm**

While soft starters are indispensable in certain scenarios, there exist strategic methods to potentially circumvent their necessity. The focus here is on preemptive measures during the design phase of greenfield projects. By adopting thoughtful planning and employing alternative solutions, engineers can potentially eliminate the need for soft starters altogether.

- **Exploring Transformer Upgrades as a Viable Alternative**

One such alternative is the consideration of larger transformers as a means to limit voltage drop during motor startups. This approach opens avenues to not only simplify the system but also potentially enhance reliability and reduce operational complexities. The ensuing discussion will delve into the economic feasibility and advantages of opting for a bigger transformer in lieu of soft starters.

Also, it’s worth mentioning, that in the realm of motor starting methods, the star-delta configuration has long been a staple. However, it's imperative to recognize that this approach is not a panacea. As we delve into motor starting strategies, it becomes evident that star-delta initiation falls short in specific scenarios. Notably, applications with demanding starting torque or those requiring exceptionally high currents may find alternative methods more fitting. This exploration aims to shed light on the nuances beyond star-delta, offering a nuanced perspective on motor starting solutions.

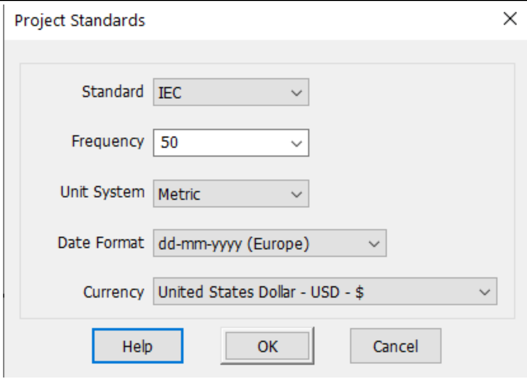
In essence, this article navigates the intricacies of transformer upgrades versus soft starters, offering insights that empower project engineers to make judicious decisions for optimized power system designs.

In the pursuit of optimizing power system configurations, our journey begins with the construction of a comprehensive model using Electrical Transient Analysis Program (ETAP). This article delves into the various aspects of the analysis conducted to determine the most efficient system configuration, considering factors like motor power, transformer load, and the need for soft starters.

1. Creation of an ETAP model, steady-state analysis and optimization.

1.1. Creation of the model

For the creation of the model in ETAP the IEC standards were used, i.e., the project used 50 HZ frequency, metric unit system and European date format. The project settings are represented in the picture bellow:



Picture 1 – Project standards

After establishing the setting of the project, the system elements were placed. The essential elements for the desired analysis are power source, transformer HV/LV, motor. Additionally, other elements such as lumped load and circuit breakers and contactors were used for convenience and to achieve the desired transformer loading. It is crucial to note that many integral elements of a real system have been left neglected for this analysis, such as, for example, cables. This was done to focus only on the field of this research and avoid unnecessary complexity of the model.

A pivotal aspect of the analysis involves optimizing the load on the transformer, ensuring it operates at an optimal level of at least 70%. This step encompasses:

- Network Configuration

Exploration of different network configurations and their direct impact on transformer loading. Consideration is given to various motor configurations to strike an optimal balance between load and stability.

- Soft Starter Impact Analysis

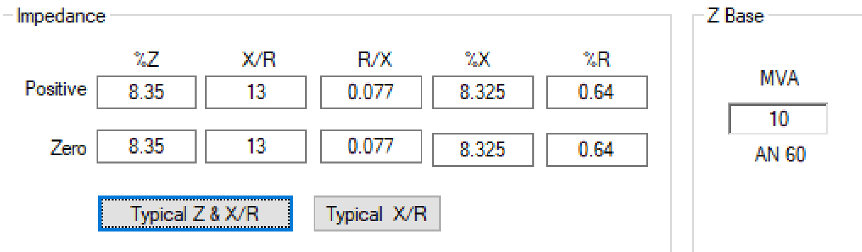
Identification of the maximum number of motors requiring soft starters based on the determined power threshold. The economic feasibility of implementing soft starters is thoroughly evaluated, weighing factors such as system reliability, maintenance, and operational complexity.

Another critical phase is the practical installation of the system, considering a load of 500 kVA at a power factor of 0.85 for SWG-0.4. The steady-state analysis is conducted to identify voltage issues and propose corrective measures, including the use of larger cables or wires and again to load transformer effectively.

System elements comments:

1. As a source of energy, the utility was used to imitate the infinite power source of 33 kV.

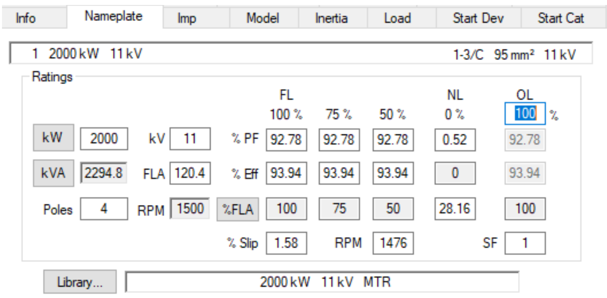
2. Transformers used are all dry type, sealed sub type, AN class, temperature rise 60. The impedance is typical that is available in ETAP as represented in the picture below for 10 MVA XFR:



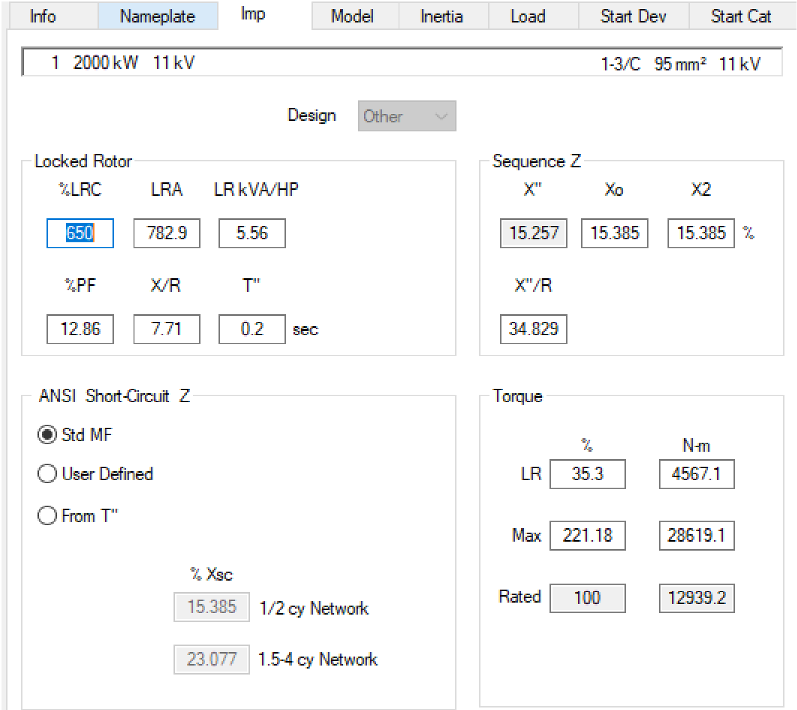
Picture 2 – Transformer impedance

3. Busses 33, 11, end 0.4 kV

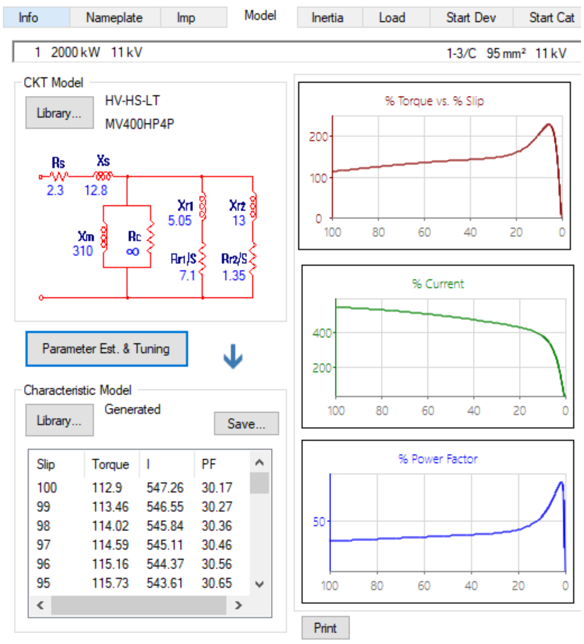
4. Motors 11KV and 0.4kV from the standard ETPA library. The following characteristics are examples of the motor 11KV:



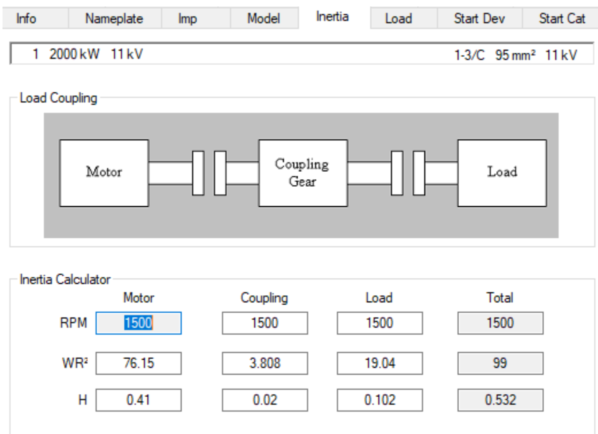
Picture 3 – Motor parameters (nameplate)



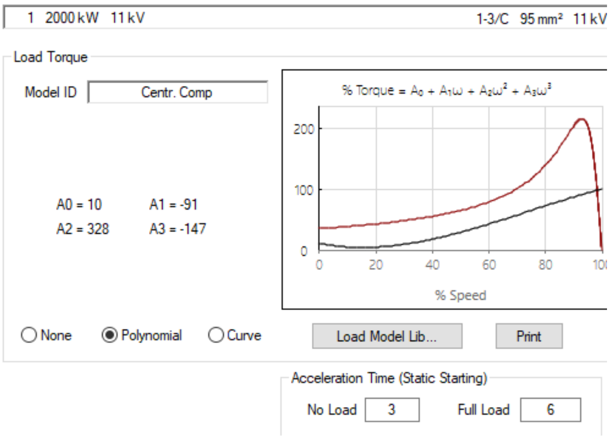
Picture 4 – Motor parameters (impedance)



Picture 5 – Motor parameters (model)

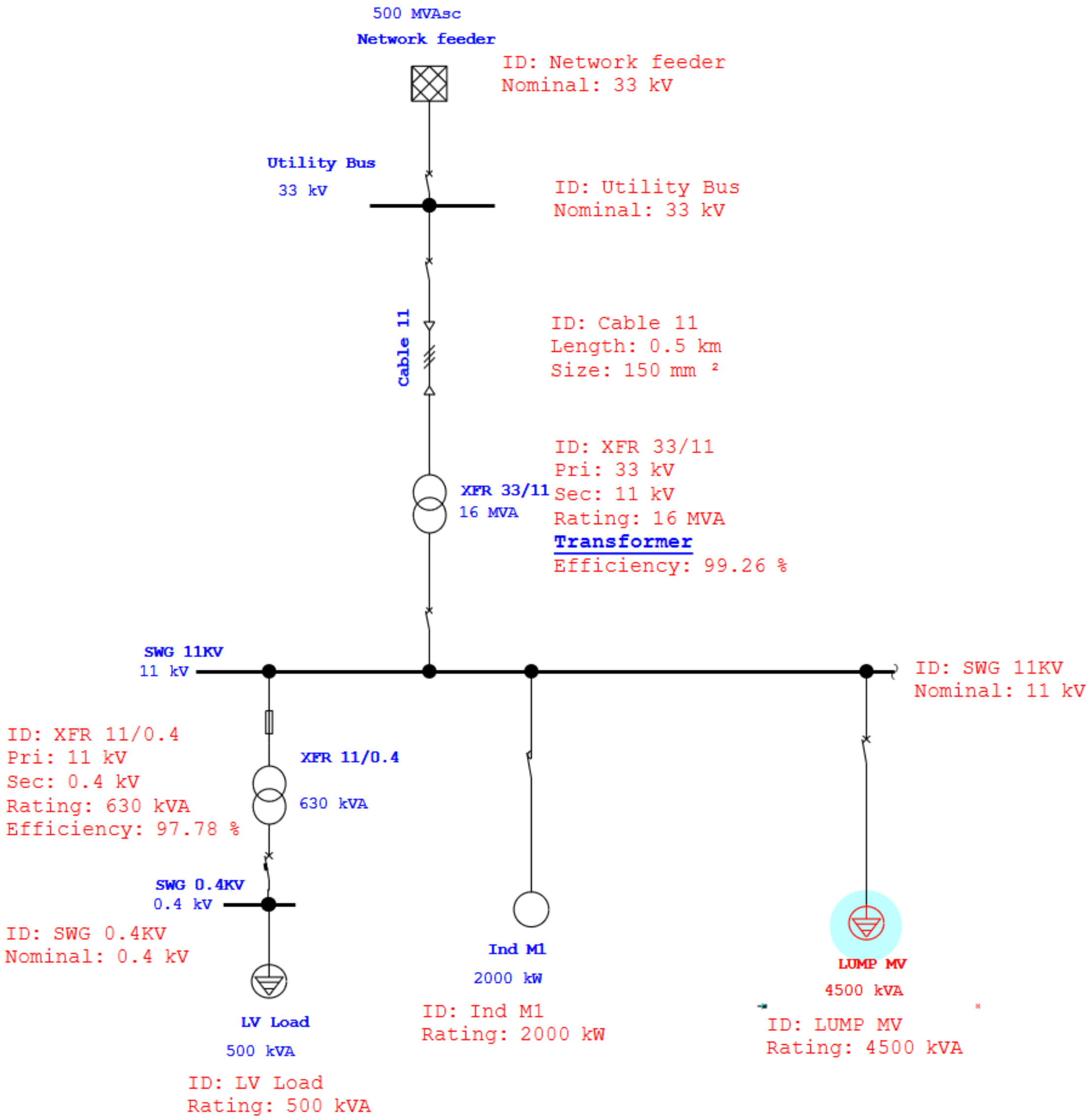


Picture 6 – Motor parameters (inertia)



Picture 7 – Motor parameters (load)

The system single line diagram (SLD) with some its parameters is shown on the picture below:



Picture 8 – SLD initial

1.2 Steady-state analysis and optimization.

For the steady state analysis, the following configuration were used:

Induction motor power Ind M1 = 2000 kW, Lump Load 4500 kVA. The objective of the the analysis is to define load flows (ensure no brunches are overloaded) and the buses voltage are within the allowable limits. In accordance with [1, p74] the permissible voltage drop between the power source and any point in the electrical installation should not exceed 5% of the nominal voltage of the power source. This value is applicable under normal conditions of steady-state operation and does not account for motor starting periods, simultaneous activation of multiple loads, and other temporary events. If this limit is exceeded, it is recommended to adjust system configuration to enter the recommended 5% range. It is important to consider that voltage drop can impact the operation of equipment, especially motors. Therefore, it is advised not to reach the maximum 5% value on circuits sensitive to voltage drop issues.

The steady state analysis shows that there is a problem with voltage of the SWG-0.4 – it is below allowable 5%.

Table 1

Load flow analysis (initial)

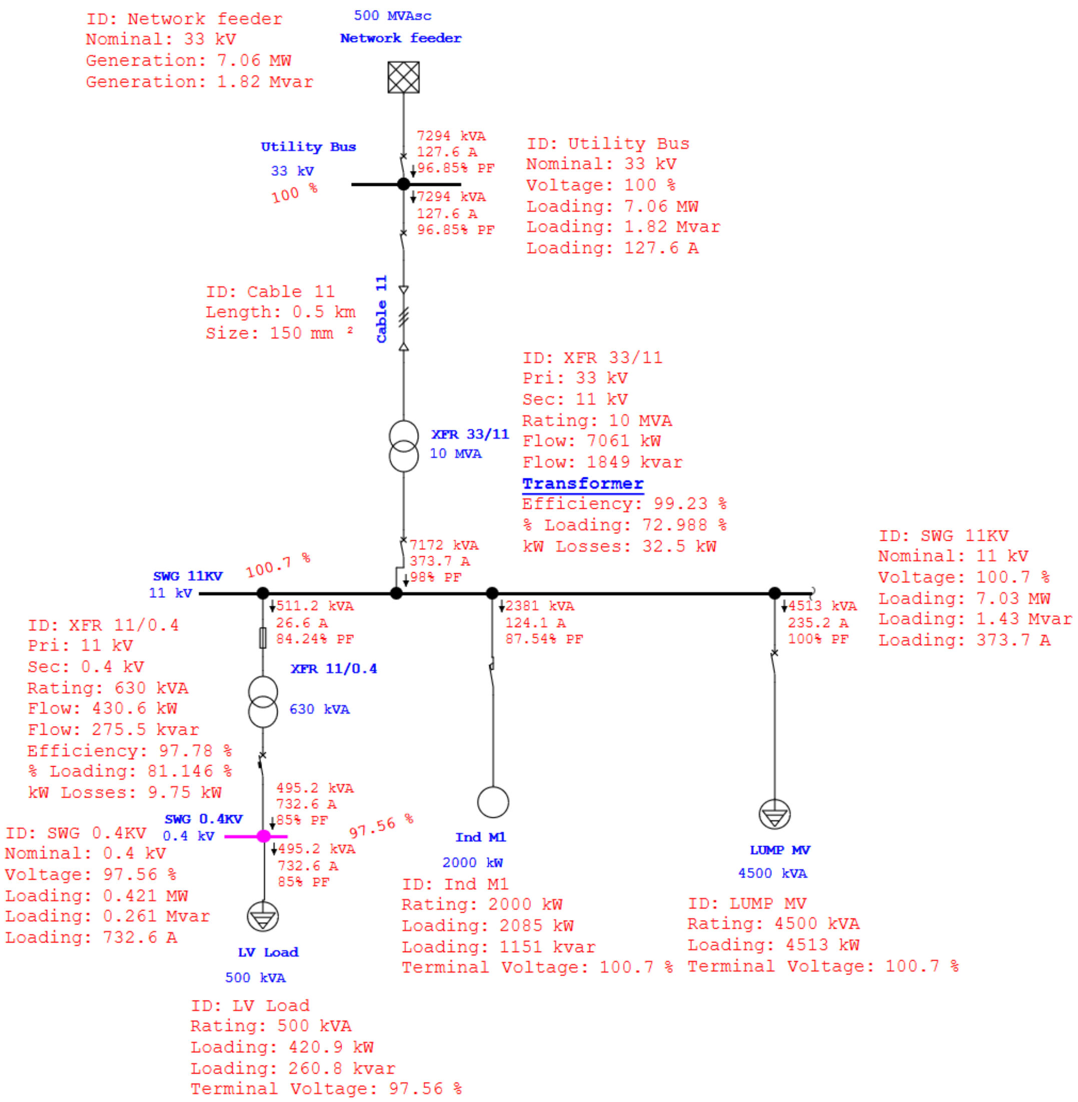
Bus ID	Nominal kV	Voltage	kW Loading	kvar Loading	Amp Loading
Utility Bus	33	100	7014.9	1831.6	126.8
HV Cable	33	99.94	7011.3	1863.1	127
SWG 11KV	11	98.11	6977.5	1424.5	381
SWG 0.4KV	0.4	94.89	416.5	258.1	745.4

As we can stabilize in both SWG voltage by applying changes in XFR 33/11 we changing (primary side -2.5) and the voltage is ok. Further increase is not practical as during summer loads the voltage will be above 105% which is desired to avoid according to IEC.

Table 2

Load flow analysis (optimized)

Bus ID	Nominal kV	Voltage	kW Loading	kvar Loading	Amp Loading
Utility Bus	33	100	7064.5	1817.3	127.6
HV Cable	33	99.94	7060.7	1848.8	127.8
SWG 11KV	11	100.72	7028.3	1426.6	373.7
SWG 0.4KV	0.4	97.56	420.9	260.8	732.6



Picture 9 – SLD optimized

2. Determining Soft Starter Necessity

To ascertain the power threshold requiring soft starter installations, a detailed study was initiated. The primary goal here is to define the power of the motor which will cause the undesired 10% of nominal voltage of the SWG 11kV. Important to mention that in steady state after motor start the transformer is kept optimally loaded, i.e., when increasing load on the HV motor, the power of the HV lump should have been decreased equally.

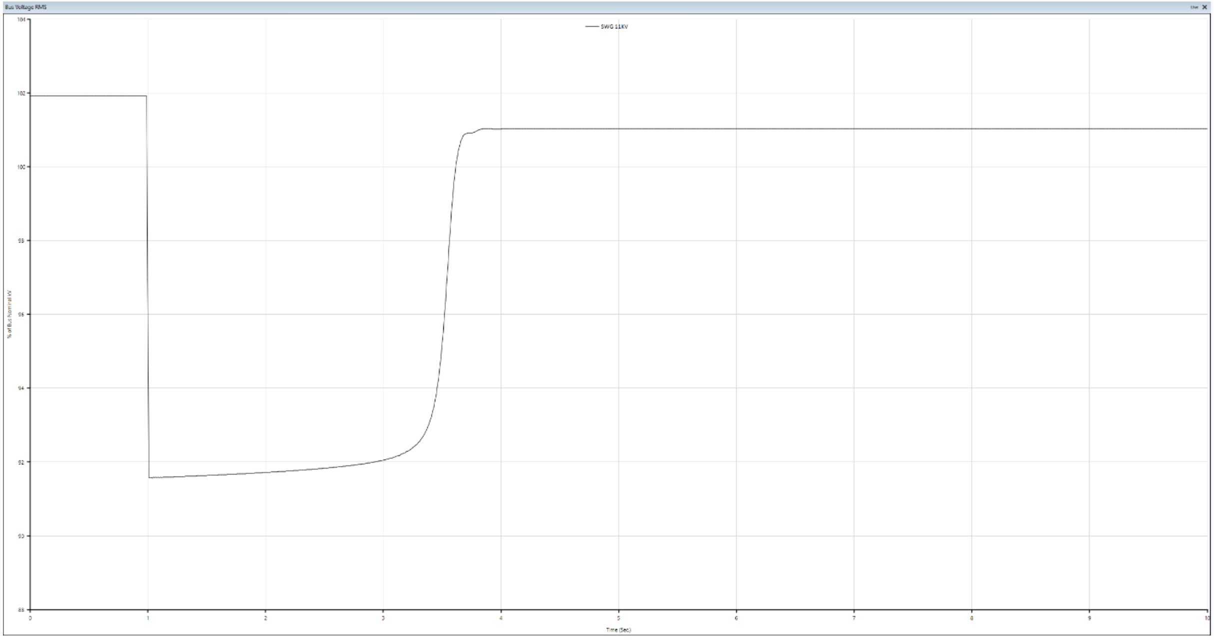
As a starting point the configuration of Ind M1 - 2000kW, LUMP MV - 4500kW has been selected.

The transient stability tool of the ETAP software was used for the calculation the voltage drops across the system during HV Motor Ind M1 start. Etap Transient Stability Analysis module fully complies with IEEE Standard 1110™-2002, [2], IEEE Std 421.5-2002, [3].

As a criterion for analysis the IEC 60076-5 was selected, namely when starting an electric motor, the allowable voltage dip at the busbars of the power supply system during the starting of an electric motor is 10% of the nominal voltage. The duration of the dip usually should not exceed 500 milliseconds [4].

It is worth mentioning that we observe a voltage deviation at 11kV. We can adjust the tap changer to improve it for the entire system and upcoming motor starts; however, we must leave some space for future growth.

For the case study event the motor normal acceleration after 1 second of steady state simulation was considered. The total simulation time was selected 10 seconds. The simulation time step was selected 0.001 sec. Below is the chart that represents the voltage across SWF 11KV during motor start:



Picture 10 – Motor Voltage during start

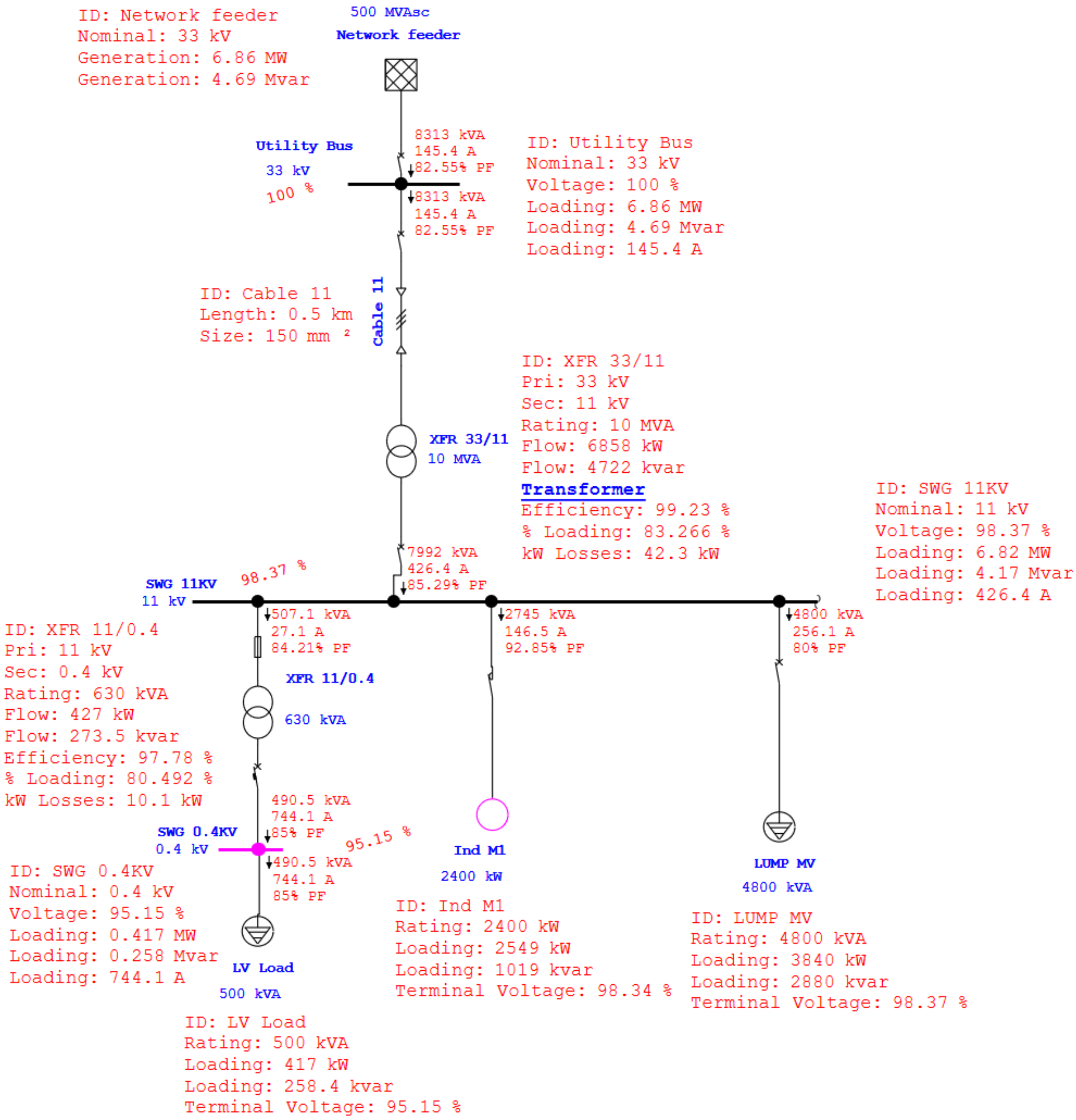
Similarly, the analysis is done for a more powerful HV motors. Empirically, It has been determined that, in our case, the observed voltage dip is considered within the maximum permissible range when the motor power exceeds 24% of the transformer power. The results are represented in the table below:

Table 3

Voltage drops for different power of the motor (10MVA XFR)

Motor, kw	Motor, kVA	Voltage drop during start, % of nomnal	% of transformer
2000	2286	8.4	23
2100	2401	8.6	24
2200	2529	9	25
2300	2629	9.5	26
2400	2744	10	27
2500	2858	10.4	29
2600	2972	10.8	30

In practical terms, it has been determined through experimentation that a voltage dip, reaching its maximum permissible level, occurs when the motor power surpasses 24% of the transformer's capacity in our specific case. This implies that, considering a hypothetical scenario where a maximum of three motors may operate at this power level on the given transformer, and given our knowledge that they will be sequentially started, we arrive at a suboptimal condition. While contemplating the inclusion of four motors, it becomes evident that the transformer would consistently be overloaded by 4.84%, with the startup phase exerting additional strain, rendering this configuration impractical. Thus, the most challenging scenario involves the sequential startup of three motors, aligning with the operational requirements of the process.

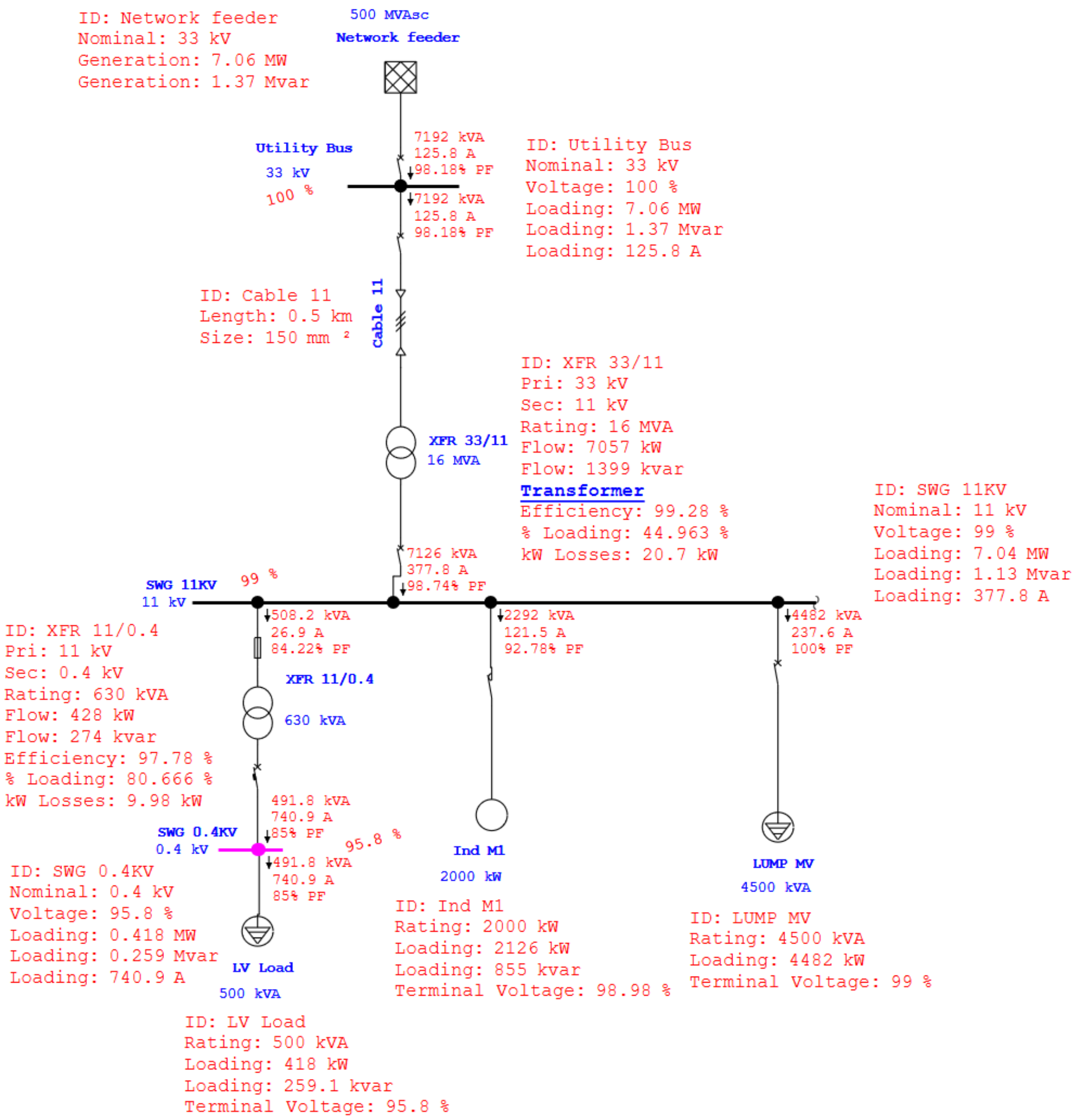


Picture 11 – SLD with data for steady-state (3 operating motors)

Essentially, the next step involves determining whether a higher-capacity transformer can effectively address the existing challenges and whether the additional cost of acquiring such a transformer would be more economical than the installation of three soft start devices. It is imperative to note that the Operations department generally exhibits reluctance towards soft start devices due to their potential to complicate the system, reduce reliability, and necessitate maintenance and repairs, all of which incur additional costs. On the flip side, a higher-capacity transformer, aside from incurring increased production and installation costs, also involves higher no-load power losses. This aspect must be carefully considered in the overall cost-benefit analysis, particularly if the transformer operates underloaded.

3. Considering the transformer 16MVA

The transformer with a power rating of 16 MVA is the subsequent consideration, and the system's operational state is as follows.



Picture 12 – SLD with data for steady-state (for a 16 MVA transformer without tap changes)

As observed, the increased power rating of the transformer eliminates the necessity to regulate voltage in the steady-state operation. Below is the table with the results for the system without tap change adjustment.

Table 4

Load flow analysis (16 MVA XFR)

Bus ID	Nominal kV	Voltage	kW Loading	kvar Loading	Amp Loading
Utility Bus	33	100	7060.4	1367.1	125.8
HV Cable	33	99.94	7056.8	1398.6	125.9
SWG 11KV	11	99	7036.1	1129	377.8
SWG 0.4KV	0.4	95.8	418	259.1	740.9

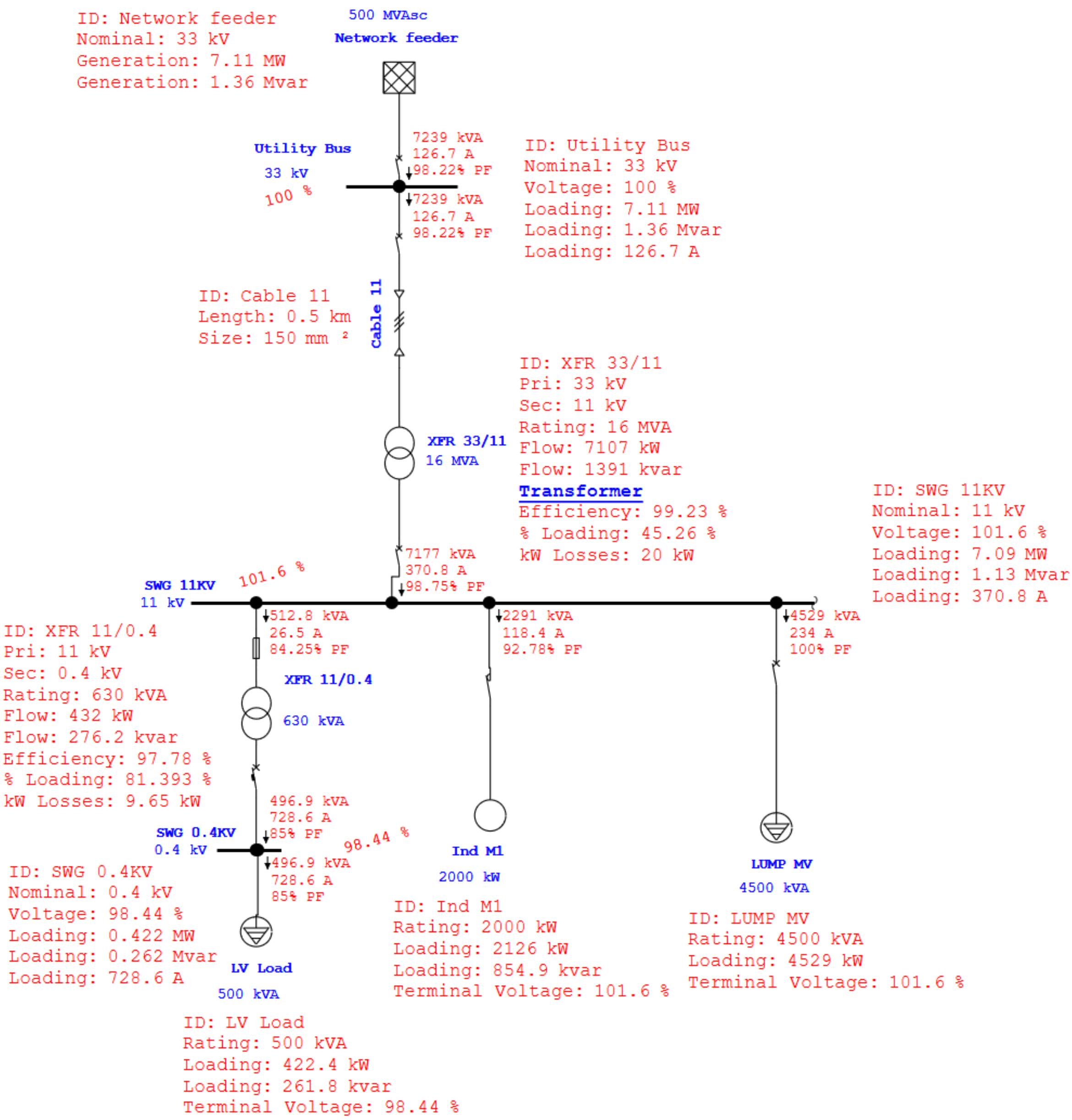
Table 5

Voltage drops for different power of the motor (16MVA XFR without tap changes)

Motor kw	Motor kVA	Voltage drop during start, % of nomnal	% of transformer
2000	2286	92,6	14
2100	2401	92.3	15
2200	2529	91.9	16
2300	2629	91.6	16
2400	2744	91.3	17
2500	2858	91	18
2600	2972	90.7	19

Simultaneously, the maximum permissible motor power can reach 2800 kW (20% of the transformer capacity) with an allowable voltage dip during startup.

If the taps of the XFR 33/11 KV are adjusted similarly to the case (primary side -2.5).



Picture 13 – SLD with data for steady-state (for a 16 MVA transformer with tap changes)

Table 6

Voltage drops for different power of the motor (16MVA XFR with tap changes)

Motor kw	Motor kVA	Voltage drop during start, % of nomnal	% of transformer
2000	2286	94.8	14
2100	2401	94.5	15
2200	2529	94.2	16
2300	2629	99.9	16
2400	2744	93.6	17
2500	2858	93.2	18
2600	2972	92.9	19

For that scenario the DOL of 3600 kW (26% of transformer capacity) motor is possible the voltage drops less than 10% during start.

In conclusion, for our scenario, it is evident that a higher-capacity transformer resolves the issue. In the case of low-voltage motors, the situation may not be entirely identical, but it is likely to exhibit similar patterns and follow analogous regularities.

4. Cost comparison

Given that a larger transformer can potentially resolve the issue of excessive voltage drop during startup, the next step involves comparing the costs of these two transformers with the costs of a soft starter installation. It's important to note that, for this article, only publicly available information from the internet was utilized. The numbers are given to represent the range of potential transformer costs, however the formula for cost effective solution is given. The price range for a 10MVA transformer is approximately $150,000 to $250,000 USD (alternative sources suggest $67,400) [5, 6]. For a 16MVA transformer, the price range could be $250,000 to $400,000 USD or more (other resources indicate $107,800). Consequently, the difference between the transformers also varies, ranging from $100,000 to $250,000 (with an additional $40,400 without delivery and installation). Therefore, if the cost of the soft starter (or two or three) is below this number it is possible to assume the solution with soft starter is more effective. There are numbers of characteristics that impacts the final cost of the electrical equipment, that is why for each particular case there should be conducted a cost comparison, at least for purchasing and installation costs. Ideally for a more precise analysis the operational costs should also be considered.

In general, the effectiveness of the capital investment can be assessed using the following formula:

$$C_{10} + n \times C_{SS} - C_{16} \geq 0,$$

where:

- C_{10} - the cost of the 10MW transformer.
- C_{16} - the cost of the 16MW transformer.
- C_{ss} - the cost of the soft starter.
- n - the number of soft starters.

If this condition is met, it implies that the cost of the 16MW transformer is comparable to that of the 10MW transformer and n soft starters, making it a beneficial and preferable solution for operations. It's crucial to acknowledge that judging the effectiveness of this solution requires detailed, updated quotes, but this method outlines a rational approach to making informed decisions.

Conclusion

In the dynamic landscape of power system engineering, the choice between implementing soft starters and upgrading transformers emerges as a critical decision. This article extensively explores the intricate considerations associated with these choices; particularly emphasizing scenarios related to voltage drops during motor startups.

As project engineers grapple with the challenge of balancing engineering requisites and operational preferences, the common reliance on soft starters faces scrutiny. The article highlights the potential to circumvent the necessity of soft starters through thoughtful planning and alternative solutions during the design phase of greenfield projects.

A substantial focus is directed towards the examination of larger transformers as a viable alternative to mitigate voltage drops during motor startups. This approach not only simplifies systems but also introduces prospects for enhanced reliability and reduced operational complexities. Delving into motor starting methods, the discussion acknowledges the limitations of the star-delta configuration and provides a nuanced perspective on motor starting solutions beyond the conventional.

Through detailed analyses, the article establishes that a higher-capacity transformer in certain cases effectively addresses challenges related to voltage drops during motor startups. It critically evaluates the cost implications, comparing the expenses associated with larger transformers against the installation of soft starters. The formulaic approach outlined ensures a methodical assessment, considering the cost of transformers, soft starters, and their numbers.

In essence, this exploration underscores the need for a nuanced approach in optimizing power system configurations. While acknowledging the potential complexities and expenses associated with soft starters, the article demonstrates that upgrading transformers can present a viable and economical alternative. Ultimately, the decision-making process should be informed by project-specific parameters and a meticulous consideration of both short-term and long-term implications.

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