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Medium Voltage Capacitor Banks Characterization and Transients Generated

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Abstract— This review presents an analysis of the over voltage electromagnetic transient's phenomena during an energizing and de-energizing of capacitor banks. The investigation has been extended to non-linear loads and distributed power systems in medium voltage electrical system. In addition, sensitive analyses of characterization impact factors have been discussed. Effects of switching transients of the capacitor bank on the regression of power quality in distribution systems have been analyzed and the results are presented in detail. The outcome of this study provides practically significant information for the power engineers that design electrical networks for medium voltage distribution systems.

Keywords— *Capacitor banks, Transients' overvoltage, Electrical grid switching.*

1. Introduction

Capacitor banks are by and large utilized as a part of both distribution and lower sub-transmission levels, to boost system capacity, decrease power losses, and enhance voltage conditions and performance of transformers at different parts in the grid. However, in spite of all important features of connecting capacitors in the field, they can also contribute to power quality problems. The switching process to energize and de-energize these capacitor banks happen often because of the system load variation or voltage fluctuation. These switching operations lead to transient overvoltage, which may damage the switching appliance identified as striking or re-striking of the switching device. The energizing of the capacitor bank causes elevated inrush current and transient voltage oscillation at the capacitor bank station [1]. Generally, the declines in service power, cost and release of system capacity are the major motivators, with loss reduction and upgrading of voltage level stability being additional benefits of lesser importance. with the trend towards a higher cost of electric power bills increased cost, and lowering of system capacity, it is expected that there will be many more opportunities for capacitor applications at the medium voltage level [2] in the future. in low voltage lv systems, capacitor banks may reduce and totally prevent power factor penalties [3]. Transients are microsecond to lower order millisecond scale fluctuations, in the steady condition voltage or current waveform. There is no obvious similarity between transients and dip or swells, though, for the plurality's fraction discussion, any occasion with a term less than half a cycle is apparently a transient [4]. in this paper, we present the issues brought out by capacitor banks during the switching operations, and characterize the transients generated.

2. Information Analysis

2.1 Capacitor units

2.1.1 Ceramic capacitors

Ceramic capacitors are obtainable in three modules confer to a dielectric constant and temperature rendering [5]. They are used in a peak frequency circuit, for example, radio frequency RF, and selection for rising frequency indemnification in an auditory circuit. Ceramic dielectric, solid or multilayer's, structure – lowest level inductance, and low equivalent series resistance (ESR), height voltage (10.0-kilo volt), doorknob capacitor, are available based on dielectric constant, temperature stability. Arrangements of class are as follows:

2.1.1.1 NPO/ COG

They are good in temperature stability [6],with positive and negative temperature coefficients, widely available, ultra steady having a low dielectric constant, costly and large

2.1.1.2 X7R/Y5R

They are reasonable size, having nonlinear variation with temperature, have 20 to 70 times as much capacitance per case size; however, the capacitance typically

2.1.1.3 Z5u/Y5u

They exceed five times the capacitance of Class two and have undomesticated swings of capacitance with voltage and temperature. The temperature varies from –25 °C to 85 °C. and capacitance change between +20% and -65% [5].

2.1.2 Film capacitors

Encompass polyester, polypropylene, polycarbonate and others. Each has its own strengths and weakness. These are normally used filters; equalizers and power supply bypass duty.

2.1.2.1 Films

Plastic film dielectric is often tubular construction and high series inductance. Polypropylene: good overall specifications, low upper temperature range of Range available 0.5Pf – 0.1µF. Operating frequency <10 MHz Rp> min (1000, 000 MΩµF, 1000, 000MΩ) [7]. The film possessions are indicative of the way that material developers are taking to create new production of plastic film [8].

2.1.3 Electrolytic

Electrolytic capacitors apply aluminum foil[9]. Metal oxide film on metal electrode and small-sized electrolyte electrode, small size. Mostly polarized and non-polarized version has half the capacitance poor temperature coefficient, and low frequency**.** Aluminum electrolytic capacitors used in the direct current (dc) link of regenerative Induction Motors IM drives. The dc-link capacitance was varied from 200 µF to 12000 µF and the source inductance from 1 mH to 5 mH for ambient temperatures of 25 °C, 40 °C and 85 °C the evaluation of the results confirmed that the lifetime of the capacitor considerably decreases while they work at elevated ambient temperatures [10].

2.1.3.1. Aluminum

Is good overall specification, low upper temperature range of higher ESR and leakage current than tantalum range available 0.1 to 2µF. Operating frequency **<** 10 MHz**,** Rp >min 5MΩ[11].

2.1.3.2 Tantalum

It has better characteristics than electrolytic but still small for high capacity values. Stable low upper temperature range of high cost; tantalum is rare metal low voltage application, low dielectric constant, large size, high Q, low series resistance high resistance to corrosion, less temperature sensitive than aluminum, more expensive than aluminum, more reliable for time than aluminum.

2.1.3.3 Silver Mica Capacitors

Silver Mica Capacitors is one of the best types of capacitors. Mica, a mineral, is one of the oldest dielectric materials used in capacitor building. There are numerous sorts of mica with differing properties, but mica is in common extremely steady electrically, mechanically, and chemically [8,12]. Mica capacitors, typically silver mica, have been highly reliable since mica has higher quality dielectric with excellent discharge resistance.

2.1.3.4 The super-capacitor (SC)

It is a very attractive storage device for working as a supplementary source of FC power. It presents very fast dynamics and can store more energy than conventional capacitors[13].

2.2 Types of power capacitor banks

Capacitor's power banks are particularly capable particular in four appearances, as follows: 1. Metal-Enclosed, 2. Pad-Mounted, 3. Stack-Rack 4. Pole-Top all of which are High-voltage shunt capacitor banks:

2.3. Request of power capacitors

A capacitor draws leading current. When linked to an inductive circuit, it offsets its inductive (reactive) component and develops the power factor of the circuit. It can be applied and accordingly categorized in two ways as follows:

- The Shunt capacitor –associated across the inductive circuit to develop its power factor.
- The Series capacitor –linked in series at the remote end to the length of transmission or all voltages of 2.4 kV. It is also on top of a high-voltage system, to recompense the reactive elements of the line impedance which includes the voltage decline and enhance the receiving end voltage.

2. 4. Ambient Temperature

For all time, capacitors are designed for switched or continuous operation in outdoor locations, with unrestricted ventilation and direct sun light. Under ambient temperatures, they are designed for mounting arrangements as shown in table (1). Capacitors are designed for continuous operation at - 40°C, and operation of capacitor banks within ambient temperature increases the life time work of the capacitor bank in the field, in addition to saving the continuity of power supply to the consumers. Nevertheless, it spares the congruity of power supply to the buyers [2]. Capacitors are appropriate for operation at their particular rating. When the ambient temperature is surrounded by limited rating, the height does not exceed 1800meters. Above sea level, the voltage applied between terminals does not exceed the rating voltage by more than the accepted rate, and the applied voltage does not contain harmonics as well as rating frequency equal to the rating source frequency [5]. If the capacitor is needed to operate in harsh environment (such as dust, fumes or vapours, under mechanical shock or vibration, high radiated

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temperature from surfaces, altitude higher than 1800 meter above sea level), the appliance request should be brought to the awareness of the manufacturer [5]. If the capacitor is essential to work on the earth, (for example, dust, exhaust or vapors, under mechanical stun or vibration, high emanated temperature from surfaces, height higher than 1800 meters below an ocean level), the apparatus demands ought to be carried to the consciousness of the producer. [6] as displayed in table (1) below[2].

Table 1: Maximum ambient temperature,[2]

Capacitors	Ambient air temperature c°	
Mounting arrangement	**24h average**	**Normal annual**
Isolated capacitor	46	35
Single row of capacitors	46	35
Multiple rows and tiers of capacitor	40	25
Metal–enclosed or housed equipment	40	25

(i) Capacitor must be tolerant to, voltage and current rating in over-load consistent with standard IEEE std.18 -2002, IEEE std.1036-1992.It should also aid in the requisition of shunt power capacitors [6]. IEEE Std. 18 -1980 give the impediments of capacitor operation at or beneath, are anticipated crises and not planned for ordinary operation.
(ii) 110% of rated rms voltage. (iii) 120% of rated crest voltage, (iv) 135% of rated rms current (nominal current dependent upon kvars and voltage), (iv) 135 % of rated kvars. Capacitor might be too appropriate for steady process at up to 135% of appraised reactive power as a result of unified consequence of:
(a) Voltage in over loads of nameplate rating at essential frequency, (b) Harmonic's voltages superimposed on the basic recurrence, and(c) reactive power manufacturing acceptance of up to 115%of appraised reactive power [7].

2. 5 Capacitor Banks

Most of the power system loads equipment are inductive in nature and thus run at a lagging power factor. When system in service at a lagging power factor the power system need extra (var) flow, with reduced system capacity, increased system losses and reduced system voltage, implementation of shunt capacitor banks in the system increase system capacity, reduce system losses,(vars) support, voltage control and reduce billing charges.

Summary of benefits of applying shunt power capacitors are divided in to two categories, namely: primary and secondary compensation. Distribution and transmission lines (examples: voltage controls, increase system capacity, reduces system power losses, and reduce billing charges), are generally considered primary benefits, while var support was secondary. In transmission system var support and voltage control are generally a primary benefits while increasing of system capacity and system losses are secondary benefits. The subsequent method can be used to calculate approximately voltage rise that capacitor will create [5]. The resulting strategy might be utilized to figure roughly voltage climb that capacitor will make [5]:

$$\Delta V_{rise} = \frac{(k\ \mathrm{var})(X_L)}{10\,(kv)^2} \quad (1)$$

ΔV_{rise} is the percentage voltage increase by the tip of the capacitor fitting; kV is the scheme line –to line voltage without capacitor in service. kvar is the three phase kilovar rating of the bank. X_L is the inductive reactance of the system at the point of the capacitor installation in ohms. The most favorable economic power factor for system, with consideration, to released capacity only, can be evaluated by using of the following rule[5]:

$$PF_{opt.} = \sqrt{1 - \left(\frac{C_i}{S_i}\right)^2} \quad (2)$$

Where C_i is expense per kilovar of capacitor banks, S_i is the expense per kilovolt amperes of scheme tools; PF_{opt} is most favorable power factor.

2.6 Capacitor in Distribution Networks

Commonly, capacitors utilized in distribution systems are situated on the distribution lines or in substations. This article expounds on the way through which capacitors are positioned on distribution lines, which may be in pole-mounted racks, pad–mounted banks or submersible installations. The distribution capacitor banks frequently comprise of three to nine capacitor units. These units are installed in three phases which are: grounded–wye, ungrounded– wye, or delta arrangement. Seeing that they are closer to the load, capacitors located on the distribution lines stand for a further effectual resource for supplying the reactive power necessities which simultaneously minimizes system losses., distribution line capacitor banks are either switched or fixed. Normally, in determining the kinds of the bank necessary strategies such as fixed capacitor banks are sized for minimum load conditions, while switched capacitor banks are contagious for load levels above the minimum condition. Up to crest load, capacitors found in the distribution lines stand for further effective assets for supplying the reactive power necessities in the meantime as minimizing framework losses. Distribution line capacitor banks are either exchange or permanent. Typically, in figuring out the sorts of bank essential for accompanying procedure, settled capacitor banks are measured for least load conditions, while switched capacitor banks are infectious for load levels above the base condition up to peak load [2]. The curve representing in Figure (1) summarized a characteristic's kilovar request over the 24-hour period. The fixed banks fulfill the base load requests, and the exchanged banks adjust for the inductive kilovar crest all around, the intensive load duration figure (1) [2]

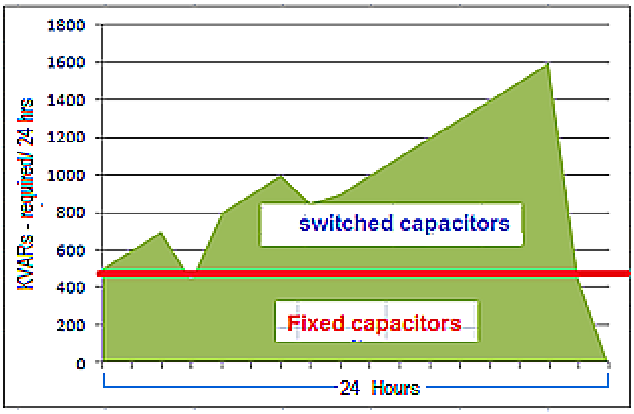

Fig.1: Switching Capacitors

2. 6.1 Sizing and location of capacitor banks

Different techniques have been planned to conclude the relative location of switched capacitors. Capacitor banks must be accurately sized to drive properly. If the capacitors are energized, at all time or fixed, care must be taken not to oversize it. If the reactive power is furnished by the capacitor exceeds the reactive power demand of the load, the power factor will be higher, which can cause poor voltage regulation resulting in high voltage during the period of light load. To avoid such leading power factors, the capacitor should be sized such that power factor does not exceed unity even when a programmed percentage of the connected load is not energized. This percentage varies with the expected diversity of the load. Therefore, a good understanding of the load characteristics is necessary for proper capacitor sizing[14]. If the purpose to reduce losses, capacitors will be coordinated with and positioned neighboring to sources of lagging vars [15]. In systematize, quite a lot of pieces of information are required to compute the necessary amount of capacitance and increase the present system power factor with particular higher power factor. In KVA or kW and power factor of the standing load, the difficulty comes from the fact that we can compute the power factor in dissimilar ways and these diverse ways influence much capacitance required to apply in a given location. A number of utilities calculate power factor as an average of the duration of fifteen or thirty minutes interval which is concurrent with the crest kW or kva demand, depending on how the interest, bills for peak demand. Other utilities accumulate kilowatt-hours and kilovars hours over the course of the month. In the previous container, one would use the power factor and the peak kW or kva during the demand interval as the requisite of kvar computation. In conclusion, one would use accumulated kWh and kvar to first compute the necessary kvars of correction needed over the month, and then divide out the hours in the month to get the required capacitor size. The objective of capacitor placement in the distribution system is to minimize the annual cost of the system. To maintain a strategic distance from extremely leading power calculates, the capacitor ought to be sized, such that the power component does not surpass unity actually when modified rate of the joined load is not energized. This rate shifts with the normal differences of the load. Hence a great comprehension of the load attributes is important for legitimate capacitor measuring[16]. When the reactive interest of a transport differs uncommonly, the capacitor must be switched. For the term of times of high reactive interest, the capacitor might be energized, and when the reactive interest reduces, the capacitor could be de-energized. In systematize, a considerable amount of data are needed to figure the important measure of capacitance and build the current framework power variable with specific higher power component. The KVA or kW and power component of the standing load, the challenge hails from the way that we can process the power figure in unique ways and these different ways can impact what amount of capacitance we require to apply in a given area. Various utilities compute power can be calculated as normal for the length of time of fifteen or thirty minutes interim simultaneous with the peak kW or kVA interest, contingent upon size. The target of capacitor situation in the distribution framework is to minimize the twelve-month expense of the grid [17], and to accomplish the most good point of interest of shunt power capacitor requisition on the spreading framework The capacitor banks ought to be spotted where they make the greatest losses diminish, supply the greatest voltage profits, and are as near the load as could be expected under the circumstances. While this is not functional, a few general guidelines have been used for placing capacitors. These embody the accompanying: (1) intended for consistently spread loads where the capacitor ought to be sited 2/3 of the separation starting from the substation. [18](2) For consistently diminishing distributed loads, the capacitor ought to be positioned one half of the separation from substation [18]. (3) Generally the maximum extreme voltage climb where the capacitor ought to be placed close to the end of the line[18]. Extra particularly, capacitor banks are essential at position where field estimations show a minimal voltage or lower power element issue. This information could be gotten as accompanies, by applying voltage estimations for the term of full-load situation at distinctive focuses on top of the feeder. The capacitor measuring mathematical statement was recorded as follows

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$$C = \frac{\varepsilon A}{d} \quad (3)$$

Where, C=capacitance in farads, ε= permittivity of dielectric (absolute, not relative), A= area of plate overlap in square meter, and d = distance between plates in meters.

$\varepsilon = \varepsilon = \varepsilon_o K$

Where, ε_o= Permittivity of free space, $\varepsilon_o = 8.8562 \times 10^{-12}$ F/m, K= dielectric constant of material between plates.

2.6.2 Selection of capacitor

There are many factors that influence the selection of the capacitor banks in distribution system, these factors include: precision, stability, percentage of leakage and breakdown voltage which minimizes temperature with the rate of time.

2.7 Capacitor banks connection

There are five regular capacitor banks connections. The favorable connection depends upon the most excellent employment of the standard voltage rating additionally, preventive relaying practically on each and every one substation banks are linked in wye. Allocation capacitor banks, may though be linked, wye or delta. The different types of connections illustrated are in figure (2), its explain the different ways of capacitor banks connection in the grid [19].

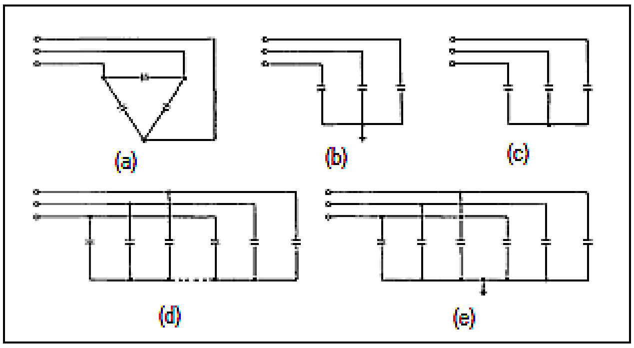

Fig.2: Capacitor bank connections [20]

2.7.1 Delta connection banks

Delta joined banks are ordinarily utilized just at load power system voltage and arranged by a single series assembly of capacitors estimated between two-line voltage, since they require two –bushing capacitors with a protected rack.

2.7.2 Grounded Y - connected banks

The Grounded Y capacitor banks are gathered or arranged in sequences. Paralleled, joined capacitor units for every stage give a low-impedance path to ground as figure (3) shows the externally fused capacitor bank unit and ordinary bank arrangement plans [19].

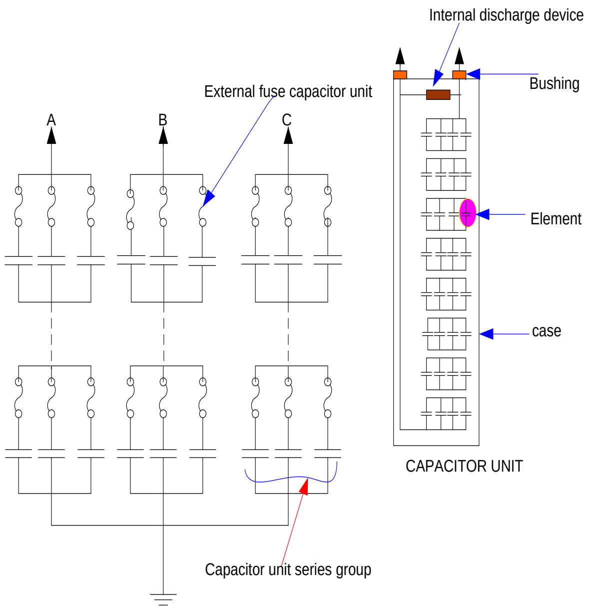

Fig.3: Externally –fused capacitor units [20]

2.7.3 Ungrounded Wyes- connected Bank

Ungrounded wye banks do not permit zero sequence currents, third harmonic currents, or large capacitor discharge currents during system ground faults. (Phase-to-phase faults may still occur and will result in large discharge currents.) The neutral point of the bank, however, should be insulated for full line voltage because it is momentarily at phase potential when the bank is switched or when one capacitor unit fails in a bank configured with a single group of units or during close-in system ground fault [7].

2.7.4. Ungrounded Split –Wye

This design is corresponding to ungrounded wye format. The split–wye link method is widespread because it is simple to reveal unbalanced at the neutral[20].

2.7.5 Grounded/Ungrounded Wye Merit

Majority of distribution and transmission-stage capacitor banks are wye linked, whether grounded or ungrounded. Characteristics of a grounded bank are as follows:

(a) It offers low impedance for lightning surge currents.
(b) It offers a degree of protection from surge voltages.
(c) It diminishes recovery voltages for switching equipment (Roughly twice normal crest voltage)
(d) It gives a lowest level impedance to be ground for triple and further harmonic currents.

Characteristics of an ungrounded bank are as follows:

(a) It does not provide a path for zero-sequence currents, triple, and other harmonic currents

(b) It does not provide a path for capacitor discharge currents during system faults.

(c) It requires the neutral to be insulated to full-line voltage [21].

(d) It unbalances assurance with a straightforward uncompensated transfer since any system zero sequences grouping part influences both wyes equity. Yet a failed capacitor units show up as unequal in the neutral.

2.8 Size and number of banks

Capacitor bank's necessities are conclusive by enhancing the profits for a given position of system prerequisites. Capacitor principles are frequently assumed as continuous variables whose expenses are measured as proportional to capacitor size by past researchers [22] [23]. However, commercially obtainable capacitors are separate capacities and tuned in individual steps[24]. Furthermore, the expenditure of the capacitor is not linearly proportional to the size. Therefore, if the incessant variable approach is used to select essential capacitor size, the technique may not result in best possible clarification and may still lead to unwanted harmonic resonance state. Many works have been studies by several researchers on the capacitor in a balanced distribution system. Few studies has been done on capacitor placement to the unbalance distribution system [25, 26]. Distribution substation capacitors are habitually measured to provide the var need of the load supplied by the substation transformer bank. The point when the capacitor bank is energized or de-energized, the essential system voltage builds or reduces correspondingly, to have a negligible impact upon purchaser loads. This voltage change is frequently limited to value in the range of 2% to 3%. The voltage change ΔV in percent can be to estimate by the following rule [5]:

$$\Delta V\,\% = \left(\frac{M\ \text{var}}{MVA}\right)100\ \%$$

(4)

Where

Mvar = the Mara size of the capacitor bank.

MVAsc = the available three –phase short circuit MVA at the capacitor location.

The base bank size is affected by the accompanying elements, capacitor bank, unbalanced contemplations, and fused coordination. The point where a capacitor works to show a fizzled capacitor, an unbalance condition can happen that subjects units in the same group to 60 Hz over voltage. A regular criterion to the farthest point is over 110% voltage with one unit out. This obliges a base number of units in parallel as is given in table (2). IEEE Std 18 -1992 show that a capacitor might reasonably be foreseeable to withstand throughout typical administration life Table (3) indicates a joint sum of 300 provisions of power frequency terminal. The terminal over voltage without a superimposed transient or harmonic presents of size and spans.[5].

Table 2. Minimum recommended number of units in parallel per series group to limit on remaining units to 110% with one unit out.[5]

Number of series groups	Grounded Y. or Δ	Ungrounde d Y	Split ungrounde d Y
1	-	4	2
2	6	8	7
3	8	9	8
4	9	10	9
5	9	10	10
6	10	10	10
7	10	10	10
8	10	11	10
9	10	11	10
10	10	11	11
11	10	11	11
12	11	11	11

Table 3. Maximum permissible capacitor voltage [5]

Duration	Maximum permissible voltage(multiplying factor to be applied to rated voltage rms)
6 cycles	2.20
15 cycles	2.00
1 s	1.70
15 s	1.40
1 min	1.3

2.8.1. Bank Configurations

There are three capacitor bank setups which are grounded wye, ungrounded wye and delta. Delta associated capacitors are normally only utilized at low voltage 2.4kV where standard capacitor rating is not reachable for wye association. To a large extend, wye- joined capacitor establishments are less perplexing to construct and more practical. There are specific points of interest related with grounded against ungrounded capacitor banks. The favorable contrasting circumstances between grounded-wye and ungrounded wyes are:

(a) First expense to the bank may be minor as the unbiased does not need to be separated from ground at full framework BIL.

(b) Capacitor switch recovery voltages are decreased.
(c) Mechanical obligations, for instance, seismic may be less brutal for the construction. [5]

2.8.2 Installation of shunt capacitor banks

Establishment of shunt capacitor banks might be made without any purpose of the system, when estimations are carried out and harmonic's mutilation is known. The determination of the compensation techniques could be made as individual compensation capacitor banks which can be joined straightforwardly to the terminals of customers. Group's compensation capacitor banks can be joined to the distribution system that sustains a number of singular burdens, and central recompense capacitor banks in substantial establishments where numerous unique loads work.

2.9 Capacitor banks protection

To ensure convenience of a capacitor bank, administration requires dependable security which guarantees least harm to the bank in the event of a shortcoming. The banks ought to be segregated from the system before it is sternly harmed or passed to a shortcoming created within the framework. The outline of the capacitor bank defensive framework might as well recreate attention impact of seven crucial conditions:[19].

- Over current due to capacitor banks bus faults.
- - System surge voltages.
- Over currents due to individual capacitor unit failure.
- Continuous capacitor unit over voltages.
- Discharge current from parallel capacitor units.
- 6 - Inrush current due to switching.
- 7- Arc-over within the capacitor rack.

2.9.1 Selection of the capacitor units fused

The essential purposes in selecting a capacitor fused are:

- The fuse should be able to withstand steady state and transient currents in order toavoid spurious fuse operations.
- The fuse must efficiently remove a failed or failing capacitor unit from service without causing further damage or disruption to the capacitor and the system. [27].

2.9.2 Group fusing

Group fuse can be explained as one fuse prevents more than one capacitor from damage. As shown in figure below, commonly employ in pole mounted distribution capacitor racks.

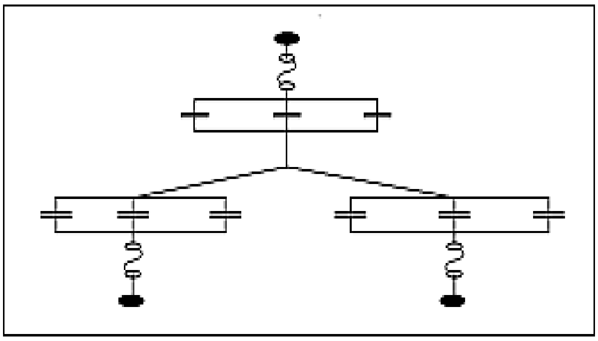

Fig.4: Group fusing arrangement in wye connected ungrounded capacitor bank with three capacitor unit per phase.

2.9.3 Individual fusing

In these types of construction, each capacitor in a bank being protected by individual fused as explained in figure (5), commonly employ in outdoor substation capacitor banks. It comprise of individual fusing arrangement in wye connected ungrounded capacitor bank with three capacitor units per phase.

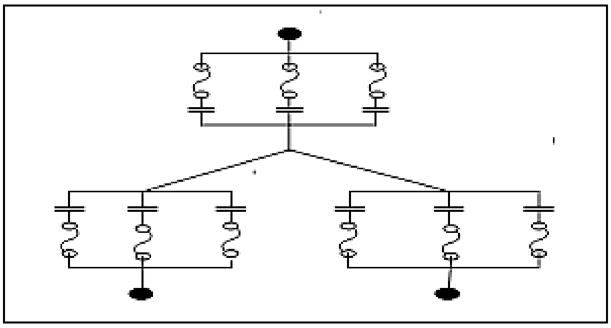

Fig.5: Individual fusing arrangement in wye connected ungrounded capacitor bank with three capacitor units per phase.

The capacitor –unit fused ought to be chosen to [19]:

- Accommodate the greatest capacitor unit-current taking into account system overvoltage, capacitor unit tolerance, and harmonics current.
- Withstand transient outrush current from substantial capacitor units that happens, when near the capacitor bank is energized (back –to- back switching) and when the neighboring capacitor unit faults.
- Operate as quickly as could reasonably be expected according to climbing capacitor unit failure and in all cases react totally. In some occasions, it may be unpredictable to select the capacitor unit to fuse that will meet these targets and, in such cases, exchange offs amidst the different criteria ought to be made. Allude to the breaker production or capacitors fabricate for.

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2.9.4 Capacitor specification items of standard

The following is a synopsis of items that should be specified by purchase. If the bank is to have to provision for increased ratings in the future, the purchaser specification must also comprise meaning of items for future circumstances in addition to the degree to which these necessities are to meet in original design and equipment of the bank. the continuity of capacitors banks Service require the following conditions , ambient temperature requirements for outdoor and indoor equipment, power system frequency, maximum power system operating voltage, (phase to the grounded insulation requirements per IEEE or IEC standards, for example, BIL, switching surge withstood, leakage distance). Rated reactance of each segment or sub segment, (current rating for the bank inserted mode, continuous current, emergency over load current and durations, swing current and duration) current ratings for the bank bypassed mode, continuous current, emergency overload current and durations, swing current and durations, fault current and durations. Overvoltage protection, types of over voltage protective device, protection and control and safety.

2.9.5 Bank over current protection

Protecting capacitor bank versus the major fault, such as a line to line or line to ground fault, in general need a number of forms of external protection such as power fuse breakers or circuit switches linked relay circuits., Figure (4), (a) and (b) show types of over current protection. Capacitor bank can operate indefinitely at current levels in excess of that based on rated kvar and voltage. The backup protection should allow 125% or 135% of rated current to be carried persistently. [19]. The bank fused design protection is divided into three categories as follows: fuseless, internal fused, and external fused., Externally fused capacitor banks have higher failure voltage and currents than fuseless or internally fused banks, because an external fused blowing causes the loss of a whole units. [19]. [28].

3. Types of Transients Generated by Capacitor Banks

There are two major sources of transient's overvoltage on the utility system. Internally generated transients up to 80% of transients are generated from interior source such as inductive load switching. Usual equipment operation and capacitor switching as well as a numerous of other switching phenomena are at receiving end of user services. Some power electronic devices generate considerable transients when they are switched. At least 20% of transients are originated from external sources such as lighting. It can be concluded that the transient's phenomena are classified as medium frequency. Electromagnetic transient's power system transients, founded on waveform shapes, can be categories into oscillatory transient and impulsive transients. The occurrence of surge or transients is not intentional, unlike an impulse as will be noted later and may appear as a result of system disturbance such as during:

-A lightning strike.

-A switching operation and fast bus transfer (a direct on – line switching is a single transient condition, whereas quick bus transfer is off and on i.e. a double transient condition hence more severe).

-Due to the surge transference from higher voltage to the lower voltage side of power transformer.

-During faults such as ground fault in the resonant grounded system or an isolated neutral grounded system. The above mentioned was explained and numerate the originated of transients in the whole power system distribution and transmission. However, there are many types of transients generated due to the capacitor banks switching as denoted by the following:

- Switching of a shunt capacitor banks which may switch during the faults conditions.

- Back to back switching, i.e. switching of a second capacitor banks on the same bus in presence of an already energized bank. It could be presumed that the transients' phenomena are considered medium frequency electromagnetic transients transients. [29] [30]. Figure (6), [31] show comparison between exact expression (solid line) and approximation (dashed) for transient amplitude due to capacitor energizing.

-Tripping or de-energizing a bank under normal operation and under fault operation conditions.

-Possible secondary resonance when the capacitors are applied in multi-voltage level (i.e. at 13.8kv and 480 low voltages) in the distribution power system. Restrike and prestrike in the switching devices.

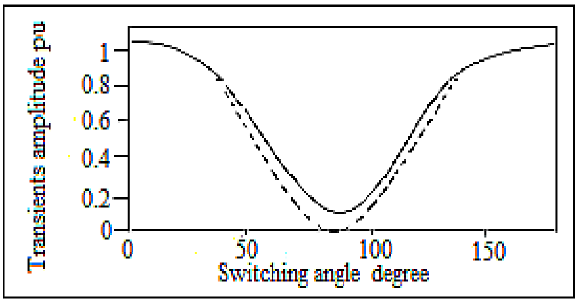

Fig.6: Transient amplitude. [32]

3.1 Normal switching transients

Normal switching transient can be modeled as opening or closing of ideal switches in linear RLC circuits. The four switching procedures of significance as follows: 1. Capacitor energizing, 2. Capacitor de-energizing, 3.

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Inductor energizing, and 4. Inductor de-energizing. The majority severe case from a power excellence viewpoint is the energizing of the capacitor.

3.2 Capacitor –energizing transients

The link of the capacitor to supply leads to damped oscillation superimposed on the new steady-state voltage. An expression for this oscillation is obtained by using the circuit as shown in figure (7).

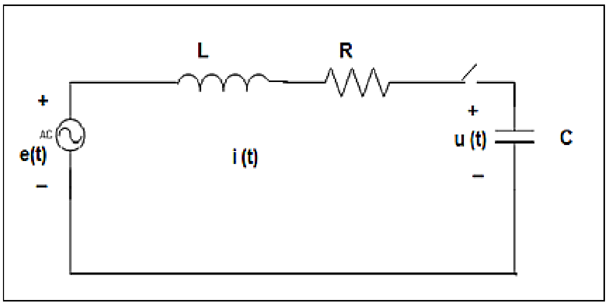

Fig.7: Capacitor energizing circuit

The magnitude of transient is large for cost ψ =1.That is when switching takes place near the maximum of the system voltage. A small magnitude is obtained when the switching takes place around voltage zero, where the latter is called synchronized switching.

3.3 Capacitor switching

Capacitor switching is a standout amongst the well-known switching events on the service systems. Capacitor is utilized to give reactive power. Whilst the capacitor bank is energized or de-energized, current and voltage transients are processed that impact together the capacitor and the connected system. To redress the power factor this diminished losses and boosts the voltage of the system. They are an exceptionally temperate and habitually inconvenience-free method of fulfilling these objectives. Alternative techniques, for example, the utilization of rotating machines and electronics var compensators, are substantially unreasonable or have high support cost. Hence the utilization of capacitors on the systems is much switched normal and will keep on being. One hindrance to utilization of capacitors is that they yield oscillatory transients when switched. A few capacitors are energized constantly (fixed bank), while other are switched consistent with the loads' levels. Figure 8 show the transients overvoltage at the low voltage system LV. When switching the capacitor banks at time 0.085 second using PSCAD simulation software, the graph show the phase voltage in low voltage system**.** Figure 9 show the line current.

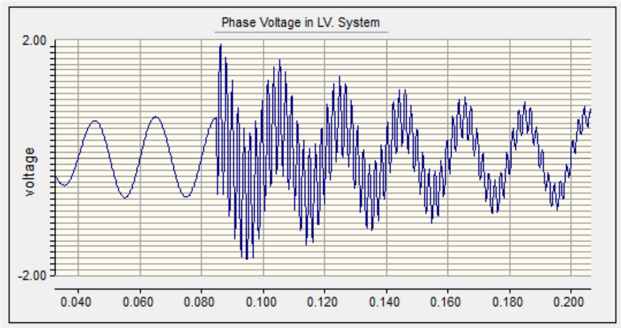

Fig. 8: PSCAD simulation software for phase voltage in low voltage system when capacitor bank switching at time 0.085 seconds, 480 volts

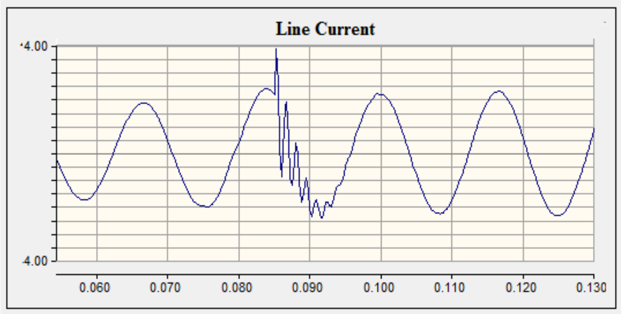

Fig.9: PSCAD software simulations when switching capacitor banks switching in distribution system. Line current at time 0.085 second. source voltage (480 volts)

The capacitor bank switching at t= 0.085 second, and the capacitor current rings resulting in a ripple in the load voltage. The ripple in the load voltage due to the capacitor

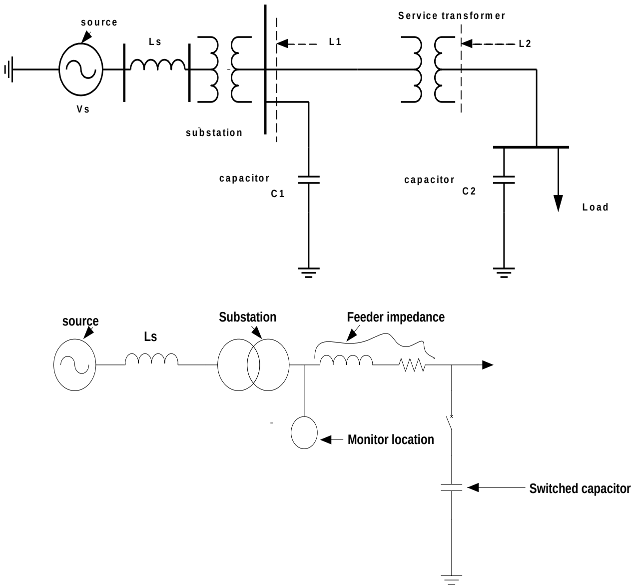

Fig.10: One line diagram of capacitor switching operation

current that rings at the resonant frequency of LC circuit, the line neutral voltage 277 volt. Figure 10, show an isolated capacitor bank model One line diagram of capacitor switching operation, figure 11 show the capacitor banks switching circuit diagram control, in addition figure 12, presented the PSCAD simulation for energizing capacitor banks at line to line voltage graph , (MV)system 11kV circuit breaker switching at 0.085 second, in order to figure13, show Voltage magnification at customer due to energizing capacitor at utility system or energization of two capacitor banks back to back switching figure13Illustrated the equivalent circuit.

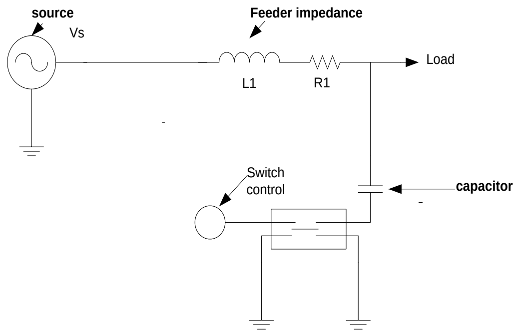

Fig.11: Capacitor banks switching circuit diagram

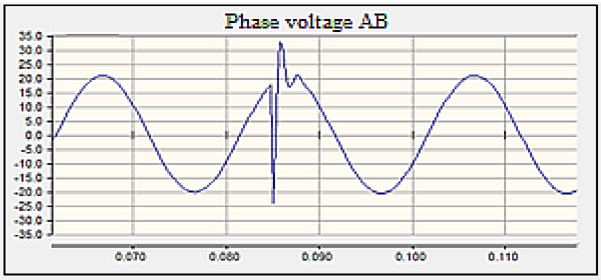

Fig.12: PSCAD simulation for energizing capacitor banks at line to line voltage graph , (MV)system 11kV circuit breaker switching at 0.085 second

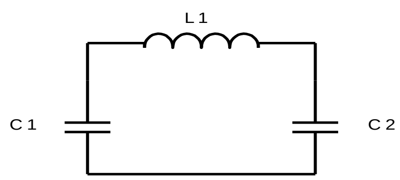

Fig.13: Equivalent circuit of capacitor energized

The first-stage capacitor banks C_1 is already energized and linked to the system bus. The energization of the second capacitor C_2 with the same rated as back –to- back switching into the bus during closing switch of $C_{2,}$ double actions of transient phenomena happen, and can be illustrated as follows:

(i) First transient phenomena action**:**

Whilst the switch is blocked to energize the second bank C_2, the charge stored in C_1 is discharged to C_2 and therefore, the charge is shared between two capacitors. For the duration of this very speedy occurrence, the current from the power system is ignored. The equivalent circuit is represented by the inductance of the loop between C_1 and C_2 or L_1 in series with capacitances C_1 and C_2 as shown in Fig. (14).

Figure .14 Volage magnification at customer due to energizing capacito at utility system

In this incident, the worst case happened after C_1 is completely charged to the crest system voltage or V_P and C_2 is completely discharged. The surge impedance Z_0 and peak inrush current from C_1 to C_2 can be planned by using equations (1) and (2) correspondingly. [1]

$$Z_0 = \sqrt{\frac{L_1}{\left(\frac{C_1 \times C_2}{C_1 + C_2}\right)}} \quad (5)$$

, the inrush current,

$$I_{inrush} = \frac{kV \times \sqrt{2}}{\sqrt{3} \times Z_0} \quad (6)$$

the frequency of inrush current and oscillating overvoltage is calculated by:

$$f_{1\,Inrushcurrent} = \frac{1}{2\pi\sqrt{L_1 \times \left(\frac{C_1 C_2}{C_1 + C_2}\right)}} \quad (7)$$

the voltage across the capacitor is calculated by using this equation below :

$$C_1 V_1(0) + C_2 V_2(0) = (C_1 + C_2) \times V(\infty) \quad (8)$$

Where:

V_1 (0) and V_2 (0) are initial voltages stored in $C_{1.}$ C_2 V (∞) is the final voltages of both capacitors after charge sharing. By neglecting the damping, voltage across C_2 swings to 2 times of common voltage. Thus, from the above equations, the inrush transient current can be reduced by increasing the inductance or using pre-inserted resistor to damp the oscillation.

(ii) Second transient phenomena action

Subsequent to distributing the charge, jointly capacitors reach the general voltage and iterate to the supply potential. Through the re-establishment, oscillations happen due to the source inductance, L_S and both capacitors in parallel. The equivalent circuit of this incident is obtainable in Fig. (12) The frequency of restoring oscillation and inrush current of this event can be determined by

$$f_2 = \frac{1}{2\pi\sqrt{L_S \times (C_1 + C_2)}}, \quad (9)$$

$$I_{inrush} = (V_P - V(\infty)) \times \sqrt{\frac{C_1 + C_2}{L_S}} \sin \omega_2 t \qquad (10)$$

The crest oscillation voltage V_{peak} is greater than that of the first incident, is obtained by

$$V_{peak} = V(\infty) + 2(V_P - V(\infty)) \qquad (11)$$

for the duration of these two transient incidents, the supply voltage remains almost unaffected[1]. Figures (15) and (16) show the simulation graph of Power System Computer Aided Design PSCAD software simulation for inrush current at medium voltage 11 .0 kV Transient voltages and currents throughout energization and de-energization are considerably dependent on the circuit breaker operation. The inrush currents and overvoltage considerably reduces without multiple re-ignition among circuit breaker contacts during its closing operation[32]. Figure16, and 17 illustrated the line and the phase current during the energization of back to back capacitor bank in the system, using PSCAD software simulation when back to-back capacitor bank energization inrush current.

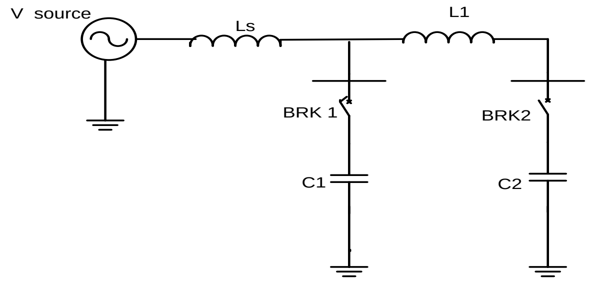

Fig.15: circuit of second transient action

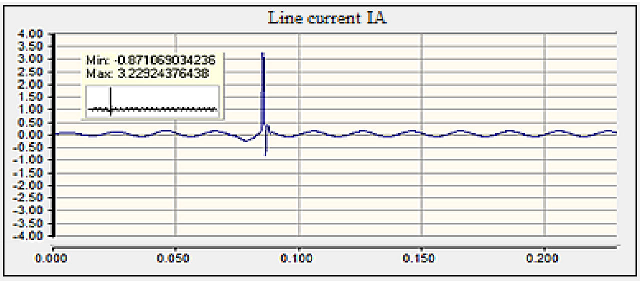

Fig.16: PSCAD software simulation when back to-back capacitor bank energizationn inrush current in LV-system

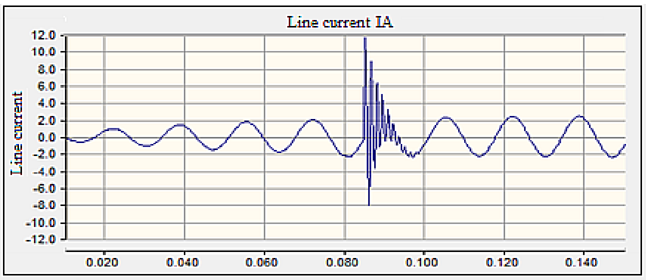

Fig.17: Simulation of back to back inrush current at MV system

3.4 harmonic effects

Harmonic harms may influence in failures of capacitor units, blown fuses, and broken control of the transformer in addition to misoperation relays. The use of shunt power capacitors to develop the system in use efficiencies also has a considerable influence on harmonic orders. Capacitors do not create harmonics, but offer network loops for possible local or general resonance forms. Capacitors influence the magnitudes of harmonic's voltages and currents that occur on the service system in addition to the consumer's loads. Problems with harmonics often show up at capacitor banks. The main reason for this is that capacitors form the resonant circuit that magnifies harmonic current's levels causing highest voltage distortion. The highest voltage distortion in the resonant circuit occurs at the capacitor bank. This cause of elevated capacitor currents at harmonic frequencies and overheating due to extreme rms current is one of general failure type. Fuse blowing can also occur due to high harmonic current in the capacitor bank. The rms current through a capacitor can be increased substantially by harmonics even when little voltage distortion exists from the low capacitor impedance at harmonic's frequencies. [33] The main anxiety arising from the use of capacitors in a power system is the possibility of system resonance. This outcome imposes voltages and currents that are significantly elevated than would be the case without resonance. The reactance of capacitor bank decline with frequency, and the bank, hence, acts as a sink for higher harmonic currents. These belongings increase the heating, and dielectric stresses. The effect of increased heating and voltage stress shorten capacitor life span[34]. Critical methodology of reducing harmonics created by capacitor banks, occur by utilizing arrangement series inductance and resistance, pre-insertion impedance and synchronous switching. The optimal worth of safety for pre-insertion impedances could be resolved from this mathematical statement:

$$R_{optimum} = \frac{1}{2}\sqrt{\frac{L_S}{C}} \qquad (12)$$

The inrush current

When the initial inrush current occurs, the peak magnitude of the current calculated by using the formula:

$$I_{PEAK} = \sqrt{2} E_{l-n} \sqrt{\frac{C}{L_T}} \qquad (13)$$

I_{PEAK} = maximum peak value inrush current, E_{l-n} = line to neutral RMS voltage. C = Equivalent capacitance, in microfarad (μF). Ls = source inductance (μH) line to neutral. L_T = total inductance (Ls + L bank)

Inrush frequency:

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$$f_r = \frac{10^6}{2\pi\sqrt{L_T C}} \tag{14}$$

The frequency and magnitude of inrush current resulting from the energizing capacitor bank are dependent on: (i) the point on the applied voltage wave when contact close. (ii) Capacitance and inductance of the system. (iii) The charge of the capacitor at closing time and (iv) damping resistance. There are many techniques accessible to mitigate transients, one of these synchronous of circuit breaker during back -to -back capacitor switching. This equipment had the advantages of closing each pole independently near zero–crossing of the voltage wave form. The second pre-insertion resistors and current limiting reactors (CLR) reduce transients to levels that would not influence the equipment[35]. Current limiting reactor are positioned in series with capacitor banks to limit the rate of rise of current to standards particular in circuit breaker regularity [36].

3.5 Types of others problems due to capacitor bank

There are numerous sorts of others issues due to capacitor banks. Establishment in the electrical system prompts the accompanying impacts in the power distribution network. Several problems can happen during the substation throughout the energization of back-to-back capacitor banks. Mainly those in the majority generally applied grounded wye arrangement. In the common cases, high neutral current flows are in charge of cause. Neutral current flow takes place throughout switching because of the unbalance produced by non-simultaneous pole operation of the switching device [36]. A restrike of a substation capacitor bank throughout opening of the capacitor switch can cause higher transient voltages both at the substation and at remote feeder capacitors. There are five essential sorts of waveform contortion: 1-Dc –offset 2- harmonics 3-inernal harmonic 4- notching 5 – noise.

3.5.1 Impacts of capacitor banks switching in the systems

The methods utilized for lessening the impacts of capacitor banks switching could be sorted into two primary mixed bags. The primary group holds a system that is utilized to moderate the impact of capacitor bank's switching, and the second bunch holds gadgets utilized to avert parameters that expand and break down these impacts. Transient over voltages and over current concerning capacitor exchanging are customarily arranged by crest greatness, frequency and duration These parameters are supportive for assessing conceivable effects of these transients on power framework equipment[37] . Transient's overvoltage secured from shunt capacitor exchanging development may cause undesirable effects on client supplies. Illustration of these effect's tripping of changeable pace drives, methodology controls, and any heap which cannot endure sub cycle transients.[38]. Association of capacitor banks brought about electrical transients. Due to the phenomena of electric charging; these reasons effects impacted the accompanying. Severe harmonic's deformation and resonance with load, created consonant, and this influences the purchaser equipment. Increment of the transient's inrush current of power transformers in the framework creates overvoltage which leads to the network unsettling influences, reduction power component and further losses in appropriation feeders. Harmonic currents prepared by nonlinear load were injected back into the supply frameworks. These flows can cooperate unfavorably with an extensive variety of power network supplies.

4. Discussion

In 1993, (McCoy & Floryancic, 1993) used analytical information to derive actual measurements. In addition to exploring complete information in breaker sizing, capacitor bank's design and fault current for implementing trust worth installations. Their work also provided prudence into what happen when capacitors are switched on and off at a medium bus. The transients switching on a medium voltage bus did not cause any serious transient voltage condition. This is only sure if the installation is designed correctly and prepared with circuit breaker designed for capacitor switching. However, several factors were not considered throughout this work. These factors include the injection traveling wave due to the capacitor transient switching, dielectric stress, losses due to the placing of capacitors and the influences on energy preservation and availability resulting from the capacitor size, harmonic effect. There is, therefore, the need to develop strategies and find a solution to reactive power, and loss control resulting from the effect of energy conservation, and availability resulting from the size, location, and design of capacitor equipment.

The works of (Tusaliu, Teixeira, & Pinto, 2003), in 2003 used different line models, consider the Pi and frequency-dependent models for the transmission lines using software called EMTPDC/PSCAD. This investigation should imply that transient’s recovery voltages are affected by the power system equivalent parameters. The use of different line modes gives different results. The connection of neutral on earth has great influence in the maximum transient’s recovery voltage when the neutral point is solidly grounded and when the neutral point is grounded through the capacitor. This investigation did not look into factors that affect TRV waveforms at the switch during de-energization across the circuit breaker. Besides, there is that need to analyses the influences of DC Voltage mode and the charges that stay within the lines, the voltage waves at the open end of the line during de-energization and switching anomalies. Information for proper operation of breakers should also be developed. The result of using

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Electric Magnetic Transient Project (EMTP) simulation to analyses and control switching transients was discussed by (Das, 2005). Pre-insertion resistor and series inrush limiting reactor can control the limiting and prediction of transients. The simulated (EMTP) without lumping of system elements, give a reliable outcome of surge transference, propagation, decay, magnification, and secondary resonance through the distribution system.

The simulation did not include transient frequency waveforms, capacitor banks sizing. Transients delay time, transient's peak time setting time of transients, and the influences of the lines' lengths. In this work, the characterization of transients' waveforms, transients' magnitude and transients' duration needs to be determined. (Tan2009) used Tokic, and Uglesic, in 2010, used MATLAB/ Simulink to perform sensitive analysis on the system parameters. They disregarded the residual voltage in the equivalent three-phase electrical simulation model by reducing the system impedance, increasing the load, increasing the capacity of the capacitor banks twice, and moving the moment of the circuit breaker switching in phase two for 0.1 ms. [35]. The study did not consider transient energy and methods of limiting transient over voltage waveforms (amplitude, duration and frequency). The result obtained was classified as transient generated by capacitor banks (as medium frequency electromagnetic transients). As a future work, the study intended to look at the location on the capacitor banks by increasing or decreasing with the distance from the load or end user substations. Consistent with a regular hypothesis of capacitive is current switching the most intense obligation for capacitors banks (CBs) results from energization of capacitor banks. Power system transients get unmistakable in differing waveform shapes and are by diverse crucial explanations. Consecutively to better comprehend their source, it is critical to investigate as per their underlying reasons or event. The routines utilized for diminishing the trapping effects of the capacitor bank switching: It might be ordered into two significant aggregations, first strategy used to mitigate the impact of capacitor switching. Also other techniques are utilized to anticipate parameters that fix and exacerbate an impact. Besides different issues that impact on the power, transient was recognized notwithstanding the optimal systems methods used to end the transient. Switching near the peak amplifies transient's voltage and current. Indeed, as in the region of zero intersections decreased them, they found measure understood the inrush present of single isolated capacitor banks and in addition the back-to back inrush current. It is noteworthy for office planner or specialist to realize what sorts of transients could be available in an electrical network. Additionally, it is important to be conscious of affectability of the installation equipment for such transient, switching activities, either to join, isolated loads or to switch off failure section before a short circuit, and turbulence from outside. For example, a lightning strike on or in the encompassing region of high-voltage transmission lines. This case electrical transients and likewise, prompt over voltage and high inrush current, arrangement and shunt capacitor banks are connected to create the dependability level of system and additionally to diminish the surge impedance.

5. Conclusion

There are several considerations involved in the characterization of transients generated by capacitor banks. This paper investigates and discussed, transients and other electrical abnormalities created by capacitor banks. In view of the past studies on electromagnetic transient's phenomena, a phrase should here is a processed transient in voltage and current waveforms. This inconveniences incited by switching a capacitor banks closed to another formerly in administration are becoming high crest transient voltage and inrush current.

Power system transients show in altered waveform shapes and are caused by different implied reasons. In order to better grasp their origins, it is significant to characterize transients according to their underlying events. An initial characterized has been given where oscillatory, and multiple transients are further classified according to their underlying causes. This study was concentrated on characterizing and explicates oscillating transients generated by capacitor bank switching in medium voltage levels, based on such previous studies. We modeled the oscillatory transients as the sum of damped sinusoids, where the signal was treated. The decayed apparatus of damped sinusoids can be used to extract information or to understand the fundamental sources and, therefore, for developing solutions of power system transients.

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