Electrical Power Generation System: Optimal Design for Medium-Load Industries with High-Rated Generators

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Abstract — The demand for electrical power is rapidly increasing due to the rise of industries in developing countries. Power generation stations are having troubles to strike a balance between demand and generation. In this situation, it is urged that appropriate remedial action be taken. Rising power demand can be met by designing an efficient electric power generation system which will also help lowering the generation cost. It is shown that while high rated electric power generators are connected in parallel the value of neutral current is rising and the cooling temperature is also increased. Here, the goal of this experimental work is to present a new model for designing an efficient power production system for average-load (ranging up to 8000 Amp, 440 V) industries to minimize the demand on centralized interconnected grid. A scheme is proposed with four generators (2500 kVA, 2000 kVA, 2000 kVA and 1250 KVA) in parallel and enough cooling arrangement is provided with minimal cost. The coolant temperature is maintained 61 °C to 61.5 °C and at that time diesel temperature is not more than 38.5 °C. The amount of neutral-current is also optimized (up to 8.5 Amp.) which was more than 12 Amp. At the morning and afternoon, the neutral current is almost constant, but it is bit fluctuating between 7.5 Amp to 8.2 Amp at mid-day. The final outcome shows, the suggested system is efficiently stable with the change of load and generates optimal electricity.

Keywords — distributed generation, generators, load conditions, medium load industry, power generation optimization.

I. INTRODUCTION

The power system is the most complicated system in modern life, with direct implications for modernization, economics, politics, and social issues [1]. Electric power networks have a variety of obstacles, including less efficient, higher energy waste, high pollutants, and a significant risk of economic power abuse [2]. The gap between wholesale energy market pricing and retail tariffs in typical flat electricity tariffs leads to inefficient resource utilization since consumers are not incentivized to change their usage according to supply prices [3]–[8]. Furthermore, demand in electric power networks has a high peak to average ratio (PAR) [9]–[11]. As the peak hours are only a minimum

number of hours per day, substantial investments in generation, transmission, and distribution systems are required to meet peak demand, resulting in higher power generating and electric power supply costs [2].

As the developing third world countries are marching forward to become developed nations, power demand is rapidly increasing due to the high rate of industrialization. Many industries in developing countries like Bangladesh have land shortage and the power crisis is a concern for its growth [12]. Efficient power generation system can help industries by lowering the generation and transmission cost of electrical power which also helps these industries to maximize their production capabilities. Designing such an efficient power system is the most important step in this direction. The demand, or the amount of power consumed in KW, is always taken into account in the design.

Climate change has major influence on the power grid. The whole world is facing various kinds of natural calamities due to climate change which affect power systems on many different levels, including transmission and distribution [13]. Various power generation methods are presented, and some solutions are quite efficient. This is a significant shift in power system architecture, which has hitherto relied on massive, concentrated power plants. Problems arise when renewable energy sources are used as supplementary support for a power system since the sources are not easily available. Because renewable power generation technologies must coexist with existing power systems, integration issues arise. Increased use of distributed generation (DG) units, which include both renewable and non-renewable power sources like photovoltaic (PV) or solar, wind turbines, wave generators, fuel cells, and gas/steam powered Combined Heat and Power (CHP) stations, is being driven by a drop in inflation (and thus increase in cost) of fossil fuels, rising demand for electricity, and government policies aimed at reducing greenhouse gas emissions [12]. Bangladesh, like other countries, is eager to enhance its power infrastructure by utilizing renewable energy sources. However, in order to meet the power demand, competent generating technologies must be used, with the ability to mitigate the aforementioned issues.

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The increased demand for electricity, on the other hand, necessitates changes to the existing power generation system. It has already been demonstrated that when high-rated generators are coupled in parallel, the neutral current increases rapidly and becomes difficult to manage, as well as the temperature. At previous set up the neutral current was 12 Amp. and while the set up was running for long time the neutral current was more than that [11]. Hence, this current study was aimed to design a reliable and efficient power generation scheme with a view to minimize the neutral current and the temperature of the centralized interconnected generators and generate electrical power with cost minimization.

II. PROBLEMS WITH THE CURRENT POWER SYSTEM AND PROPOSED SOLUTION

A. Limitations of Existing Power Systems

There are a number of constraints with power systems. The power situation is worsening by the day as a result of these limits. The primary drawbacks of current power systems can be described as follows [12], [14]:

1) Ineffectiveness

Approximately 8% of total generated electricity is lost via transmission grid lines, and 20% of the capability of power generation is available to satisfy peak demand. The efficiency is low due to the considerable transmission loss. Other losses in the present power system exist in addition to transmission losses. The current power grid is inefficient in this regard.

2) Failures of Domino – Effect

It's a hierarchical arrangement in which power plants at the top make sure power gets to customers' loads at the bottom. In short, power is only transmitted in one way, resulting in large-scale blackouts due to power plant failures or transmission line problems. The most well-known power outage in Bangladesh happened in November 2014, when cascading incidents caused 100 million out of 160 million customers to lose power for 10 hours [18], [19].

The following data was collected for a 2500 kVA generator:

- Manufacturing Year: 2011.
- Power Rating: 2500 kVA.
- Current Rating: 3609 amp.
- Voltage Ratio: 400/230.
- RPM: 1500.
- Temperature (Maximum): 30 °C.
- Voltage of excitation: 47 V.
- Essential current for excitation: 5 amp.

The design of the system is represented by Fig. 1.

3) Destabilization

System stability is being harmed by unusual fluctuations in demand for electrical power, as well as increasing DG penetration and lagging expenditures in electrical power facilities. Power generation systems are forced to run at the commencement of oscillation due to load demand and a lack of transmission capability. Low frequency electromechanical oscillations caused by unbalanced mechanical torques owing to perturbations (load and topology fluctuations) can impede power sharing between areas and lead to load shedding if they

are not adequately reduced [15], [16]. As a result, a model is designed for an efficient power system to match the consumers' power consumption demand [4]. The model of an efficient power generation system is addressed in detail in the next paragraphs, and then the focus of this work is on the obstacles of constructing such a system. We use a reference model for this, which is discussed in the next section.

B. System Architecture

The model is designed for medium-load industries in Bangladesh that use high-rated (KVA) generators. The generators in the proposed system are rated at 1250 kVA, 2000 kVA, 2000 kVA, and 2500 kVA, respectively. These four generators have four separate exhaust system, but they are sharing a common fuel tank and a common storage tank. All the generators are wired to maintain parallel connection. Every generator can be controlled separately. There are some mechanisms are also maintained to reduce the vibrations of these generators.

The system design is shown below in Fig. 1.

Fig. 1. Proposed model for power generation system.

The proposed approach maximizes the utilization of area and equipment for a more efficient power production system for medium-load industries that require 5 or 6 MW. This model includes a few unique features, which are detailed in the subsections below.

1) Compact Shape

In most cases, medium load industries have limited space for electrical power generation. So, the first priority of the design is to address the space shortage and designing a system that can be built in compact spaces. A compact space system is essential for reducing land size, as well as making power generation more cost-effective and efficient.

2) Shorter distance between generation and load

According to the distance rule of resistance, wire resistance increases as the distance between a generating station and a load center increases, resulting in transmission loss. Because the generation and load centers in this proposed system are so close together, power loss is greatly reduced. As a result, the most efficient and effective power generation and distribution are achievable.

3) *Cost savings on conductors*

Transmission networks lose about 8% of total generated electricity, and only one-fifth of total generation capacity is available to meet peak demand. Because of the significant transmission loss, the efficiency is low. In addition to transmission losses, there are other losses in the current power system. In this aspect, the current electrical grid is inefficient.

4) *Minimization of heat and excess noise*

For human safety, an appropriate heat and noise margin level must be maintained for a 6.2 MW power generating station. To keep noise levels between 85 and 95 dB, a silencer box is used. Heat reduction is achieved by radiators and exhaust pipes.

5) *Air intake and exhaust properly*

The total air requirement for four generators exceeds 7,00,000 cm³. To meet the demand for needed air, a centrifugal blower system is created to be installed at the front side of the chamber. To accomplish the needed level of air intake, high-pressure blowers are used. The system has four exhaust pipes and three blowers on the back side to move exhaust and heated air outside of the space.

6) *Size reduction of fuel tank*

The temperature of the generator's inlet should never exceed 40 °C. For cooling, a heat exchanger is employed in this model. The cooling system is attached to the generator's return fuel (200 L) line to cool the fuel when it reaches temperatures above 60 °C. As a result, the heat is absorbed by the water in the cooling system, and fuel from the return line returns to the tank at its optimal temperature, which is below 40 °C. When the fuel level in the storage tanks falls below a certain threshold, fuel flows from the main tank to the storage tanks.

C. *Methodology*

An outline of the system has been presented below, as per the proposed model:

1) *Generator Arrangement*

The generators are connected parallelly and installed 10-inch-high from ground level. The spacing provided for four different generators are 7 feet, 10 feet, 14.5 feet, respectively. In running condition, generator creates vibration which is a potential cause of problems in the system. To remove this occurrence some concrete is laid directly on the top of the floor slab and the generators are mounted on the concrete pad. This concrete pad provides easy cleaning facility around the generators and a strong base level.

2) *Air Intake/Outlet*

In this model the combustion air inlet flow rate for the 2500 kVA, 2000 kVA and 1250 kVA generators are 7500 CFM, 4400 CFM, 3200 CFM, respectively. The high compressed air maintains a constant temperature. 10 exhaust fans are used to release exhaust air in the environment after circulation.

3) *Louver system*

The Louver system is installed on the right side of the generator, allowing air to circulate freely. It has a height of 15 feet and a length of 24 feet. This method keeps the

generating area cool while also reducing noise.

4) *Setup of the fuel tank*

The main diesel supply tank is located at the outer part of generator room and is linked to each generator's storage tanks. The main diesel tank has a net capacity of 90,000 L and is made up of four interconnected tanks. Each generator is equipped with its own storage tank. The storage tanks for the 2500 kVA, 2000 kVA, and 1250 kVA generators have capacities of 5800, 4200, and 2600 L, respectively. The diesel is pulled to the storage tanks and the pipes which are surrounded by motors. Two accessories are utilized at the generator fuel inlets: a control valve and a pressure gauge. Along with the motor, a control valve, a pressure gauge, and a meter are installed. The meter displays the amount of fuel flowing through the pipe, the flow control valve regulates diesel flow, and the pressure gauge measures pressure in the tank and inside the pipe. Hand valves are also utilized for maintenance and versatility.

Through the fuel return line, which is connected to the heat exchanger that cools the oil, any surplus diesel is returned to the storage tank. To keep track of the temperature, two thermometers are attached on both sides of the storage tanks.

5) *System of exhaust*

There are four cycles in a diesel engine. After a complete cycle of a diesel engine, each generator produces hot exhaust gas, which flows to the exhaust system. This system's goal is to safely release the combustion product known as exhaust gas into the outside atmosphere while posing the least amount of risk to people and the environment. The piping system, which originates from the silencer pipe, is installed 20 feet above ground level on the generator room's roof. Four flexible pipes are used to connect four generators. Back pressure is not a problem because the exhaust pipe is large enough. Exhaust pipes are insulated to minimize operator burns and reduce radiant heat loss.

6) *Heat exchangers*

Heat exchangers are used to release the heat generated by the engine into the atmosphere. The heat exchanger is not directly attached to the engine; instead, it is attached to the generator set. Electric fans deliver cooling air to the close heat exchangers, which are positioned vertically.

7) *Firefighting Systems and Equipment*

Firefighting equipment is necessary in the generator room. Ten cylinders of CO₂ extinguishers are provided in the room. Where the exhaust pipe goes through the building, fire-resistant materials are employed. Ear plugs, ear muffs, and maintenance tools are provided to those working in the room.

8) *Minimization of heat and excess noise*

Each generator has a silencer installed to reduce engine noise. It is located on the engine's upper side. Here, strict adherence to municipal noise ordinances is required at all times. For heat removal, dry type insulation is employed over the silencer and exhaust pipe. To keep the generator room cool, adequate air movement is maintained. This is accomplished through the employment of a cooling system and exhaust fans.

9) *Utility of energy*

It is important to make all the equipment function properly.

Utility energy must be used to energized important components while generators are not working. The generators' set components are maintained and started using battery chargers, turbo chargers, space heaters, and other devices.

10) Neutral Current Compensation

As all the loads in the connected system has to be provided a neutral point, 3 phase 4 wire scheme is followed in this case. The majority of these loads are unbalanced, resulting in high neutral current at both fundamental and harmonic frequencies [20]. The neutral conductor's zero-sequence current is three times greater than the zero-sequence current of each phase. Additionally, unbalanced load currents pass via the neutral conductor with zero sequence components. The Zigzag transformer was developed to correct for neutral current and zero sequence harmonic current [22]. A Zigzag transformer handles the neutral current compensation of the three-phase four-wire distribution network. The windings of the Zigzag transformers are constructed in such a way that the MMFs cancel out, resulting in neutral current compensation [23]. This analysis used a 250 kVA three-phase zigzag transformer with a rated primary voltage of 11 kV and a rated secondary voltage of 440 V.

III. RESULTS

The electrical power for three phase system can be described by the following equation:

$$P = \sqrt{3} VI \cos \phi \quad (1)$$

where V = Three phase line voltage, I = Three phase line current and $\cos \phi$ = Power factor. At the morning (8:30-9:30 a.m.) when the industry starts to run, data of voltage, current and power are recorded. This is described in Table I.

TABLE I: EXPERIMENTAL DATA OF THE SYSTEM FROM 8.30 – 9.30 A.M.

Starting time	Ending time	Total time	Avg. Voltage (V)	Avg. Current (A)	cos ϕ	Power (KW)
8.30 a.m.	9.30 a.m.	1	430	5841.17	0.81	3524
			430	6311.5	0.835	3925
			432	7115.4	0.851	4531
			432	7180.2	0.876	4706
			432	7188	0.88	4733
			435	7193.37	0.884	4791
			435	7208.7	0.873	4741
			438	7223	0.864	4734
			440	7230.34	0.881	4854
			442	7232.06	0.897	4966

TABLE II: EXPERIMENTAL DATA OF THE SYSTEM FROM 1.30 – 2.30 PM

Starting time	Ending time	Total time	Avg. Voltage (V)	Avg. Current (A)	cos ϕ	Power (KW)
1.30 p.m.	2.30 p.m.	1	432	7086.65	0.89	4719
			430	7066.3	0.887	4690
			434	7107	0.89	4755
			435	7189.41	0.92	4983
			435	7287.45	0.91	4996
			439	7372.15	0.92	5157
			441	7430	0.92	5221
			445	7554.27	0.91	5298
			442	7544.76	0.9	5198
			443	7491.29	0.92	5288
			442	7512	0.93	5248
			441	7546.47	0.93	5361
			440	7557	0.93	5356

At noon (1:30-2:30 p.m.) data of voltage, current and power are recorded. Table II shows that recorded data at noon.

Finally, at the afternoon (3:30-4:30 pm) data of voltage, current and power are recorded. Recorded data is shown in Table III.

TABLE III: EXPERIMENTAL DATA OF THE SYSTEM FROM 3.30 – 4.30 P.M.

Starting time	Ending time	Total time	Avg. Voltage (V)	Avg. Current (A)	cos ϕ	Power (KW)
3.30 p.m.	4.30 p.m.	1	435	7346.45	0.91	5064
			436	7412.7	0.91	5094
			439	7482.81	0.92	5234
			442	7514.35	0.9	5177
			447	7582	0.89	5224
			449	7559.62	0.88	5173
			446	7553	0.9	5251
			447	7604.31	0.91	5357
			446	7611.2	0.93	5468
			445	7620.3	0.95	5580

The outcome of the experiment shows that the temperature of coolant (C.T.) and the temperature of diesel (D.T.) are not changed significantly. The C.T. was maintained to keep between 61 °C to 62 °C temperature and the D.T. was maintained in between 36°C to 38.6 °C temperature. The figures are divided into two parts to describe. Three figures (Fig. 2, 3 and 4) explain the reaction of variation of C.T. and D.T. with Load in the first part, and three figures (Fig. 5, 6 and 7) describe the change of neutral current with the change of Load in the second part. The graphs are displayed below.

Fig. 2. This is a figure showing parameters like CT, DT, and NC from 8.30 am to 9.30 am (a) Variation of CT and DT with load; (b) Variations of NC with load.

At the morning time, it is observed that the C.T. and D.T. are almost constant at our set up. The coolant and oil levels are in correct level and all the generators are placed at well-ventilated area. So, the temperatures cannot exceed.

Fig. 3. This is a figure showing parameters like CT, DT, and NC from 1.30 pm to 2.30 pm (a) Variation of CT and DT with load; (b) Variations of NC with load.

At the noon, due to high temperature of external environment, it is observed that the C.T. and D.T. are fluctuating. Though due to well ventilation C.T. does not exceed 62 °C and D.T. does not exceed 38 °C.

Fig. 4. This is a figure showing parameters like CT, DT, and NC from 3.30 pm to 4.30 pm (a) Change of CT and DT with load; (b) Change of NC with load.

At the afternoon, though the temperature of external environment is decreasing but generators are running for long

time. So, it is observed that the C.T. and D.T. are little bit high. Though due to well ventilation and cooling system C.T. does not exceed 62 °C and D.T. does not exceed 38.6 °C.

IV. DISCUSSION

A Zig-Zag transformer is used to compensate for the neutral current. The neutral current and zero sequence components tend to rise with these high-rated KVA configurations. However, by employing this Zig-Zag transformer, the neutral current will be kept below 8.5 Amp. Neutral current varies very little as a function of load. Sometimes it was accurately near 7 Amp and some other times its fluctuating in between 7 to 8.5 Amp. So, these show that the neutral current is minimized in an optimal condition with these high rated KVA generators. Fig. 5, 6 and 7 show the condition of neutral current after minimization. It seems at the morning time; it is at a constant level but after the increasing of running time and load it tends to rise. Though it is minimized and kept below 8.5 Amp.

V. CONCLUSION

It is shown that by constructing an efficient electric power generating system, it is possible to meet some of the electrical power requirements while minimizing neutral current. Installations of zig-zag transformers improve the performance of the neutral current in unbalanced loads in applications where active electrical power supply is critical. The cost-effectiveness of utilizing a zig-zag transformer as a neutral current compensator makes it a viable option for small and medium businesses. The neutral current is corrected, and the value of neutral current is reduced up to 8.5 Amp. in unbalanced load conditions by using the Zig-Zag transformer, and the power quality is enhanced. The proposed system has a capacity of roughly 6 MW and can be developed to a plant with a higher capacity. Furthermore, the current system will be compatible with future generators, and proper fuel supply and air intake should be considered when installation.

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